

AFIT/GOR/ENY/98M-01

APPLICATION OF DECISION ANALYSIS TO
EVALUATE ALTERNATIVE RESEARCH AND
DEVELOPMENT INVESTMENTS

THESIS

Michael J. Artelli, Second Lieutenant, USAF

AFIT/GOR/ENY/98M-01

19980423 062

Approved for public release; distribution unlimited

APPLICATION OF DECISION ANALYSIS TO
EVALUATE ALTERNATIVE RESEARCH AND
DEVELOPMENT INVESTMENTS

THESIS

Presented to the Faculty of the Graduate School of Engineering
of the Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Operations Research

Michael J. Artelli, B.S.

Second Lieutenant, USAF


March 1998

Approved for public release; distribution unlimited

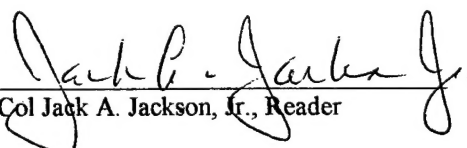
APPLICATION OF DECISION ANALYSIS TO
EVALUATE ALTERNATIVE RESEARCH AND
DEVELOPMENT INVESTMENTS

Michael J. Artelli, B.S.
Second Lieutenant, USAF

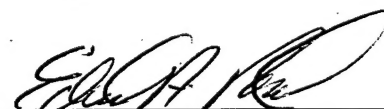
Approved:


Lt Col Stuart C. Kramer, Advisor

6 MAR 98
date


Lt Col Jack A. Jackson, Jr., Reader

6 Mar 98
date


Maj Edward A. Pohl, Reader

6 Mar 98
date

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

Acknowledgments

I want to express my sincere appreciation to my advisor, Lt Col Stuart Kramer, for his motivation, guidance, and clarity throughout this thesis. My thanks also goes to Dennis Carter whose patience allowed me the time to understand the problem. Lt Col Jack Jackson Jr. deserves credit for teaching me the principles of decision analysis. Finally, I would like to thank Maj Edward Pohl for his constructive suggestions.

More importantly I would like to thank my wife, Malisa. Without her understanding and encouragement this process would have not been worth it.

Table of Contents

	Page
Acknowledgments	iii
List of Figures	vi
List of Tables	vii
Abstract	viii
1. Introduction	1
1.1 Background	1
1.2 Problem Statement	2
1.3 Thesis Overview	3
2. Literature Review	5
2.1 Pertinent Literature	5
2.1.1 General Literature	5
2.1.2 Specific Literature	8
2.2 Conclusion	10
3. Methodology	12
3.1 Model Design	12
3.2 Model Validation	16
3.2.1 Correct Model	16
3.2.2 Validated Model Assumptions	18
3.3 Model Implementation	21

	Page
3.4 Conclusion	28
4. Example.....	29
4.1 Example Background.....	29
4.2 Example	36
4.3 Conclusion	43
5. Conclusions	45
5.1 Summary	45
5.2 Recommendations and Future Research.....	46
Appendix A Example of Multiple Objective Decision Analysis	48
Appendix B Definition of Evaluation Measures	57
Appendix C Evaluation Measure Functions.....	60
Appendix D Visual Basic Program for Automated Decision Tool.....	65
Program.....	65
Functions.....	99
Bibliography	102
Vita	103

List of Figures

	Page
Figure 3.1 Initial hierarchy	13
Figure 3.2 Final Hierarchy	14
Figure 3.3 Screen shot of evaluation measure component	23
Figure 3.4 Screen shot of weight component	24
Figure 3.5 Screen shot of data evaluation component.....	25
Figure 3.6 Screen shot of sensitivity analysis component.....	26
Figure 3.7 Screen shot of uncertainty analysis component	27
Figure 4.1 Uninhabited Strike Aircraft.....	31
Figure 4.2 Value Function of Time of Program	34
Figure 4.3 Total value for each technology.....	37
Figure 4.4 Cost Benefit analysis for example	38
Figure 4.5 Impact from changing the weight of aircraft impacts	39
Figure 4.6 Impact from changing the weight of performance	40
Figure 4.7 CDF for each technology	41
Figure A.1 Comparison of car data	49
Figure A.2 Initial value hierarchy.....	49
Figure A.3 Cost EM function.....	51
Figure A.4 Life Span EM function.....	51
Figure A.5 Total value.....	53
Figure A.6 Sensitivity of varying weight of miles per gallon	54
Figure A.7 CDF for car decision	55

List of Tables

	Page
Table 4.1 Model example data	32
Table 4.2 Uncertainty data for model example	33
Table 4.3 Weights used in the example.....	35
Table 4.4 Expected value from the uncertainty analysis	43
Table A.1 Initial car performance data.....	48
Table A.2 Value from Evaluation Measures.....	52
Table A.3 Total value.....	53

Abstract

This thesis is an application of decision analysis techniques to the problem of evaluating competing research and development investments and selecting the best portfolio from among the alternatives. In contrast to the current ad hoc approach, decision analysis provides an explicit and easily explained rationale for investment choices, complete and consistent incorporation of multiple objectives, and direct insight into the effects of uncertain investment returns. A hierarchical objective decomposition was used to capture the user's preference structure. The hierarchy was then used to develop a computer-based decision aid to allow the users to quickly and consistently evaluate technology investment options. The decision aid includes the ability to automatically perform several deterministic and probabilistic sensitivity analyses.

APPLICATION OF DECISION ANALYSIS TO EVALUATE ALTERNATIVE RESEARCH AND DEVELOPMENT INVESTMENTS

1. Introduction

1.1 Background

Today engineers must justify the money and time invested in research and development (R&D) efforts. They must also focus time and money in such a way that the efforts provide the most benefit. One reason these problems occur is the benefits from R&D projects are generally not immediately realized. Another reason it is difficult to ascertain the benefits is that there are multiple payoffs from the technologies. These payoffs may affect cost, schedule, and performance. To identify the relational effect between the attributes of schedule and cost, we can graph them. However, a better method to understand the tradeoffs of cost, schedule, and performance is through the use of multiple objective decision analysis. Decision analysis articulates the value of the benefits from an action and allows the engineer to explicitly consider the aspects that cause one R&D investment to be better than another.

1.2 Problem Statement

The recently created Air Force Research Laboratory (AFRL) is a combination of all the United States Air Force's R&D capabilities. The mission of the AFRL is "To lead the discovery, development, and timely transition of affordable, integrated technologies that keep our Air Force the best in the world" [AFRL, 1998a]. The Air Vehicles Directorate is one of ten directorates in the AFRL. The primary focus of the Air Vehicles Directorate is to improve capabilities in current Fixed Wing Air Vehicles and also develop revolutionary Fixed Wing Air Vehicle Technologies [AFRL, 1998b]. The Integration Division integrates the various functional areas of aircraft performance, in the Air Vehicles Directorate [AFRL 1998b].

The Air Vehicles Integration Division is developing a consolidated program for fixed-wing vehicle development known as the Conceptual Aircraft Systems Design and Analysis Toolkit or CASDAT [Carter, 1997]. CASDAT will be able to conceptually build a notional aircraft from an initial concept and then produce predicted flight data. CASDAT will also be able to predict the aircraft's mission performance characteristics and also show variation caused by future technology applied to the notional aircraft. Thus, CASDAT will allow an engineer to visually create a new aircraft, with new technologies, and test this aircraft against both aerodynamic principles and mission performance. Currently, CASDAT does not explicitly address the issue of the tradeoffs between cost, schedule, and performance. This research will address this shortcoming.

An analysis tool incorporating multiple objective decision analysis will allow the laboratory to properly address cost, schedule, and performance tradeoffs, as well as

provide an ability to defend the decisions. Sensitivity analysis will allow the laboratory to investigate the importance of specific technologies as well as the strengths and weaknesses of each. The analysis tool will be capable of handling uncertainty, since the true cost or performance of a technology may not be known.

1.3 Thesis Overview

The thesis contains three themes throughout its pages. This first and most important is that this is the documentation of the research provided to the Air Vehicles Integration Division. The thesis also provides a basic decision analysis overview for the Air Vehicles Integration Division. Finally the thesis is a guide to use and understand the analysis tool that has been created. These three themes can be found in the following chapters.

Chapter 2 contains a general discussion of the principles of decision analysis. This chapter begins by explaining the concepts of decision analysis that are important to this thesis, then moves to a more specific discussion of the previous uses of decision analysis to help solve the problem of R&D investments.

The Air Vehicles Integration Division's investment problem is solved by the model presented in chapter 3. The chapter explains why the model's hierarchy is structured the way it is. The model is then validated by explaining how the important principles are valid. Finally, the chapter explains the model's implementation. A Microsoft Excel program that enables the user to gain insight into the decision analysis process is developed.

The fourth chapter provides an example that verifies the model and illustrates how the model can be used. A thorough explanation of the problem leads into the interpretation of the results. These results include a deterministic approach and a probabilistic approach.

Finally, we reach conclusions about the effectiveness of the decision analysis model. This fifth and final chapter also explains areas to be improved and where future research can help.

2. Literature Review

This chapter focuses on the important literature behind this thesis. This literature review initially focuses on the broad sources of information that develop decision analysis theory. This section transitions to the literature that directly focuses on approaches to aid R&D investment decisions. Appendix A includes a thorough example of decision analysis. This chapter discusses important areas that directly affect this thesis.

2.1 Pertinent Literature

2.1.1 General Literature

Before discussing the literature that specifically applies to this thesis, it is beneficial to explain value-focused thinking and general decision analysis topics. Most decision analysis models are built using one of two approaches based on the motivation of the analyst. A value-focused model lists the important values and objectives. The second approach is known as alternative-focused thinking and does not typically identify the important critical objectives which make better decisions [Keeney, 1994:33]. This approach lists the known alternatives and then compares their values. In other words, only the good and bad points of the known alternatives are identified and used in the model. Alternative focused thinking does not directly support creating new alternatives based on satisfying important objectives. For these reasons the model used by the AFRL Air Vehicles Integration Division was created using value focused thinking. This process

lists the important objectives and then expands on these objectives until a complete model is developed.

Two requirements for a value focused thinking hierarchy are that the individual building blocks be collectively exhaustive and mutually exclusive [Kirkwood, 1997:17]. The evaluation measures are collectively exhaustive if they encompass all important attributes of the decision, and therefore model all of the areas that a decision maker needs to choose one technology over another. For the hierarchy to be mutually exclusive, none of the evaluation measures of the hierarchy are redundant and are all treated independently. In other words, the evaluation measures do not double count important attributes, and they are all separate ideas. These two properties are very important because they insure the decision is being properly portrayed and also that the weights of the evaluation measures are correct [Kirkwood, 1997: 17].

Kirkwood also writes that it is important for the model to be operable and of small size. Operability means that the user understands how the multiple levels of the hierarchy interact [Kirkwood, 1997: 18]. This is very important for implementation because if the user does not understand the weights or evaluation measures the model will not produce accurate results. Kirkwood also states it is important for the model to be small. This means with all things equal in the model's representation, the smaller hierarchy is better simply because it is easier to understand, and thus involves less confusion.

The evaluation measures of a value focused thinking model must also have mutual preferential independence to use an additive value function [Kirkwood, 1997:239]. This additive value function allows the model to be presented as a hierarchy with multiple tiers.

Also, the weight for each evaluation measure is the multiplication of all the weights from the previous tiers. Mutual preferential independence exists when, given all of the evaluation measures are partitioned into Y and Z (where Z are evaluation measures that have common levels, and Y are evaluation measures with different levels), for each Y, the rank ordering of differing alternatives does not depend on the evaluation measures in Z [Kirkwood, 1997: 238]. In other words, for all combinations of evaluation measures, the ordering of values for an alternative does not depend on evaluation measures that are the same.

The additive value function can be used when mutual preferential independence has been established. This function is,

$$Value = \sum_{i=1}^n w_i * v_i$$

where n is the number of evaluation measures, w_i is the weight of the i^{th} evaluation measure and v_i is the value of the i^{th} evaluation measure.

A decision analysis contains two steps, the first step is the deterministic stage which assumes the data is correct and certain. The second step is the probabilistic stage which considers uncertainty. The deterministic stage will produce results that can be misleading when the decision alternatives have variability in their evaluation measures. Because of this variability, the probabilistic step continues the analysis by including uncertainty in the model. The expected value, variances, and risk profiles for the alternatives can be viewed, once the uncertainty is included. The risk profile or cumulative density function (CDF) demonstrates the expected value, variance of the data, and can display dominance.

There are two types of dominance, deterministic and stochastic. Deterministic dominance is the stronger dominance because it means an alternative has no probability of ever having a value less than another [Clemen, 1996: 123]. Thus, remove the dominated alternative from the population of alternatives. Stochastic dominance relies more on probabilities [Clemen, 1996: 124]. It means that the value of an alternative for each cumulative probability is always greater than another alternative. Therefore, this alternative always has a probability of obtaining more value than the dominated alternative. This is weaker dominance because there is often a chance the dominated alternative can have more value.

2.1.2 Specific Literature

Rouse, Boff, and Thomas [1997: 389] note that, the difficulty of measuring the value from R&D investments is caused by the wide range of benefits from these investments. To measure the value for the benefits they suggest using word scales. These word scales include the benefits from both the main R&D goals and also the byproducts that the R&D investments produce [Rouse, Boff, and Thomas, 1997: 393]. They list seven types of benefits of R&D investments which range from very tangible to less tangible [Rouse, Boff, and Thomas, 1997: 392].

- Solution not otherwise possible (very tangible)
- Acceptable performance/ cost not otherwise possible
- Performance/ cost improvements
- Enhanced customers/ user perceptions and willingness to pay
- Cost avoidance
- Mishap avoidance

- Increased confidence (less tangible)

This research will focus on the benefits from performance/ cost improvements. The value from the byproducts of the investments will not be specifically addressed.

The uncertainty analysis or probabilistic phase of the analysis should follow the deterministic phase of the analysis. This allows for more understanding of the important characteristics of the decision. Barrager and Gildersleeve discuss how to incorporate uncertainty of R&D costs and performance data. They explain the uncertainty in the evaluation measures can be accounted for by using discrete approximations for the differing uncertainty. They also suggest only using three to six evaluation measures in the uncertainty analysis [Barrager and Gildersleeve, 1989: 180]. The difference in the number of evaluation measures depends on the degree of concern for the particular issues [Barrager and Gildersleeve, 1989: 181].

Clemen recommends the use of the Pearson-Tukey approximation to discretely approximate the uncertainty in the model. He states this technique works best for approximating symmetric distributions but it is robust enough to be effective for asymmetric distributions [Clemen, 1996: 278]. By using three points to approximate the continuous environment of the decision space, some data will be lost; however, the results are quite accurate, even for asymmetric distributions. The Pearson-Tukey approximation takes the 5%, 50% and 95% fractiles for the evaluation measure and then weights this occurrence of having a 0.185, 0.63, and 0.185 chance of happening respectively. A 5% fractile is the value such that the cumulative density of that value is equal to 0.05

($F(V)=0.05$). So the 50% fractile is the point where 50% of the data that can occur is less than that value.

In 1996, the Air Force conducted a value focused thinking study which focused on what technologies the Air Force needed to develop to dominate air and space in the future. This study was documented in An Operational Analysis for 2025 by Jack A. Jackson Jr., Brian L. Jones, and Lee J. Lehmuhl. The study focused on comparing various technologies on a value objective hierarchy against several alternate futures. The alternate futures used the same value hierarchy, but the weights were adjusted to represent the future appropriately. This allowed the study to focus on what technologies have the most impact over the multiple predicted futures. This research will use methods very similar to those used in An Operational Analysis for 2025.

An alternative approach to the multiple attribute value function model of R&D investment decisions is the analytic hierarchy process (AHP). AHP was not used because the process requires comparing the performance of each pair of competing technologies for each evaluation measure. Since the client is able to quantify estimates of performance and understands the value of various levels of the evaluation measures, it is better to use the multiple attribute value function [Belton, 1986: 13]. In addition, the multiple attribute value function is able to evaluate a new technology by merely entering the new scores instead of adjusting all the comparisons between each alternative for each evaluation measure. AHP can be used to ascertain the weights but is not used because the client is comfortable directly scoring the weights of the various attributes. So a multiple attribute decision analysis model has been created.

2.2 Conclusion

The insight that can be gained by properly applying multiple objective decision analysis to a problem is invaluable. To properly apply decision analysis, the model must be built insuring all the important aspects are included, and not double counting any of these aspects. These aspects also need to be preferentially independent from each other; therefore, they do not cause any interaction effect. Many decision analysis models have been created over the years; however, there has been a lack of published models that deal specifically with R&D decisions. Of the few articles that have been published, we can see that the difficulty of modeling previous decisions has been to describe the benefits from the investments. The literature also states uncertainty in the decisions can be handled by standard Pearson-Tukey approximation. The next step in the thesis is to actually model the decision and then see if the model does include the important principles.

3. Methodology

This chapter focuses on how the model is designed and implemented. The following section explains the design of the model. Then the assumptions of the model are checked for validity. The final section explains the implementation of the model in an automated computer program that is to be used by the Air Vehicles Integration Division.

3.1 Model Design

The first concern when developing a multiple objective decision analysis tool is to correctly model the decision. The Air Vehicles Directorate has been directed to improve 6 areas of aircraft performance.

- Unit production cost
- Operation and Support Cost
- Development cost
- Air Vehicle Weight
- Lift/ Drag
- Controllable Angle of Attack envelope

The laboratory's technical development approach (TDA) lists these areas [Carter, 1997].

The TDA is given to the laboratory as objectives to accomplish in the development of future fixed wing vehicles [Carter, 1997]. Initially, these six improvement goals were the basis for the decision hierarchy. Thus, we have the following initial hierarchy (Figure 3.1):

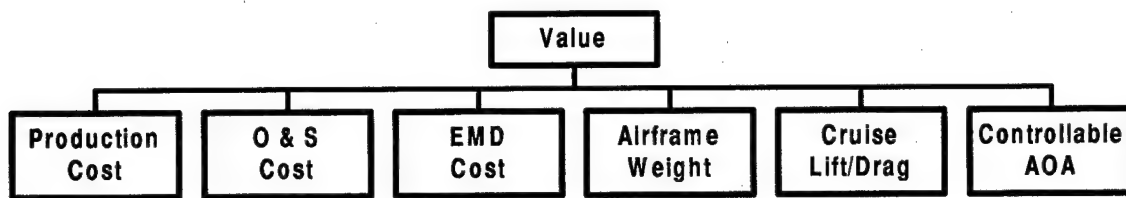


Figure 3.1 Initial hierarchy

However, this problem break-out does not accurately portray the decision structure.

Although these are all important areas of the decision, they are not collectively exhaustive. In other words, all the important issues of the decision are not properly addressed. First, the time until the technology's production is not included in the model. Also, the time the laboratory spends developing the technology is not addressed. Since these two issues are capable of changing the decision, they must be included in the model. Second, all the cost issues of the decision are not included. In spite of the fact that costs associated with the fixed wing aircraft are in the decision, no reference to the laboratory's cost to develop the technology is included. Another major concern of the TDA's objectives is the inability to truly represent all the important aspects of aircraft performance [Carter, 1997]. Some of the technologies developed will only pertain to stealth, while others will allow for more thrust. By limiting the performance issues to only lift, drag, weight, and angle of attack, the model does not accurately capture the rationale for choosing one technology over another. A final concern is the TDA is a very fluid document which is changed often. By including additional aspects the model is more adaptive to future changes in the TDA.

The objective hierarchy was modified after extensive consultations with the Air Vehicles Directorate. Several of the important characteristics that would result in a

preference of one technology over another were highlighted and incorporated in the final hierarchy (Figure 3.2). Appendix B defines the evaluation measures that are used in figure 3.2 and throughout this thesis.

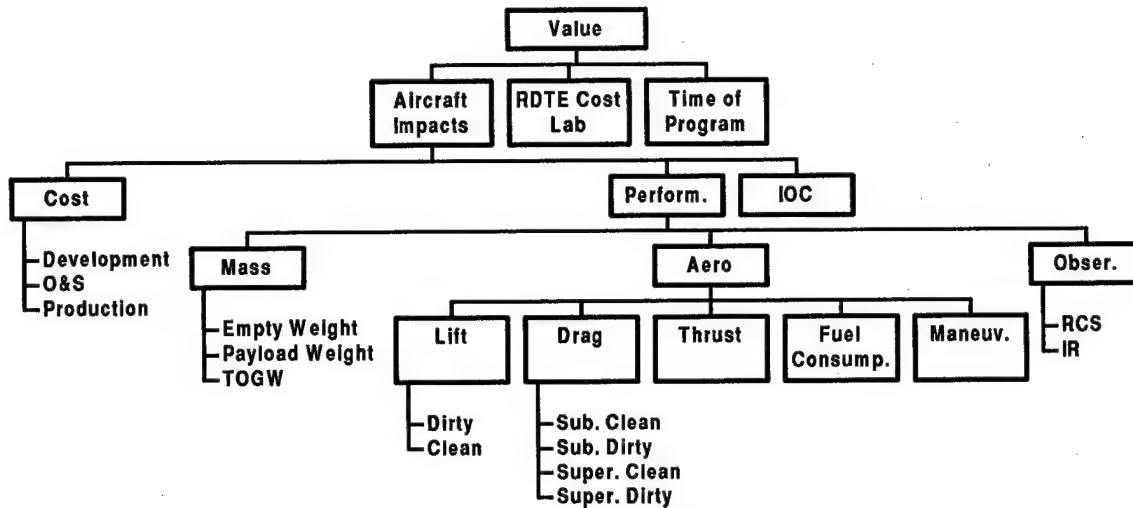


Figure 3.2 Final Hierarchy

This hierarchy can be viewed as modeling the decision from two perspectives. The first perspective is the tradeoff of the Air Vehicles Integration Division's resources against future payoffs of aircraft impacts. The second perspective contains the critical aspects of aircraft impacts which are: estimated time until the deployment of the technology (Initial Operating Capability or IOC), cost to implement the technology on a fixed wing vehicle (research, development, testing, and evaluation cost to the laboratory or RDTE Cost lab), and performance changes of the fixed wing aircraft due to the technology (Aircraft Impacts). The second perspective is focused on the technology's impact on a fixed wing vehicle with a specific mission profile, whereas the first perspective encompasses the resources that the laboratory has to spend to obtain the goals.

The cost to implement the technology is divided into three important areas. The first area is the cost to complete the technology's development after the Air Vehicles Integration Division releases the technology. This is development cost on the hierarchy. The second area is the cost to operate and support (O&S cost) a fixed wing vehicle with this new technology. The final area is the cost to purchase a fixed wing vehicle with this technology. This final cost is referred to as production cost on the hierarchy.

The performance changes are also divided into multiple areas. These areas include mass, aero, and observability. First mass involves the aspects of performance which are related to the weight of the aircraft. The empty weight of the aircraft is the weight of the aircraft with no fuel or munitions. The payload weight is the weight that the aircraft carries to complete the mission. The more bombs, missiles, and ammunition the larger this value. Finally the take-off gross weight (TOGW) is in the hierarchy because this is the weight of the aircraft when it is fully loaded and ready to take-off. This is quite different than the previous two measures.

The next area of performance is aero. Mainly, the aero characteristics involve the lift, drag, thrust, fuel consumption, and maneuverability of the aircraft. Since the lift of the aircraft changes when the aircraft has external carriage, the lift has multiple evaluation measures. This is also true for drag because it is important to know the drag with and without external carriage and also when the aircraft is flying at subsonic and supersonic speeds. The fuel consumption is a standard measure taken at sea level. The maneuverability is measured by the controllable angle of attack, which was an original objective from the TDA.

The final area of the performance section of the hierarchy is observability, which is broken into results from radar cross section (RCS) tests and infrared signature (IR) tests. Appendix B contains more detailed definitions of the evaluation measures. It is important to notice all the original TDA objectives are still represented in the updated model; however this hierarchy is better able to represent the total effect of the technology on the laboratory and also on the Air Force.

3.2 Model Validation

The validation of a decision analysis problem consists of two steps. The first step is checking that the model correctly portrays the decision. The second step of validation is checking to insure all the assumptions and theoretical basis are based on reality. Several decision makers in the aeronautical R&D community examined the hierarchy, including a representative from the Aeronautical Systems Center (ASC). Since ASC is the Air Force agency which continues R&D of the technologies created by the Air Vehicles Directorate it deemed necessary to get their participation. Dr. Squire Brown, an Aeronautical Engineer who works for the ASC at Wright Patterson Air Force Base, Ohio, verified and validated the model. Stating that it accurately represented the aspects of the decision [Brown, 1997].

3.2.1 Correct Model

A decision cannot be modeled correctly if the model does include the proper value structure. This decision maker also needs to understand the issues the stake-holders find important. Since the Air Vehicles Integration Division is the decision maker, they need to insure they are using the proper value system. Each stake-holder in a decision may have a different value structure so each stake-holder needs to be independently addressed. Three sets of stake-holders are present in this decision. The first and most obvious set of stake-holders are the individuals at the laboratory. The second set of stake-holders are the future pilots that will benefit from the new technologies that the laboratory will create. The final set of stake-holders are the United States population since the technology will eventually be used to defend the country.

If the future pilot's value structure is used, it would include evaluation measures such as bombs on target, lethality, operational readiness, survivability, vulnerability, and other measures which connect the technology to a use in war. If the value structure represents the United States population, the only concerns will be the effectiveness to defend the country, protect its assets, and the cost to do these.

The problem of whose value structure to use, has been answered by the laboratory's technical development approach (TDA). The TDA shows potential aircraft payoffs if the initial objectives are obtained. The aircraft payoffs include:

- Reduced acquisition costs
- Increased lethality
- Increased mission range

- Increased operational readiness
- Reduced vulnerability

These are the values of the future pilot and are directly related to the values of the United States population. The laboratory does not directly model these payoffs because some are very nebulous and all are dependent upon each other. By incorporating the TDA's goals, the laboratory is able to provide important payoffs to the nation and also justify their R&D investments. Thus the laboratory's value structure adequately represents all of the stakeholders.

The value of human life is a concern the model does not specifically address. This is important when comparing technologies involving an unmanned aircraft versus a single pilot aircraft. The unmanned aircraft does not directly put a human life in danger's way, so there is less cost if the aircraft is lost. Therefore, the decision maker must include this issue into the model to make the final decision. This issue was not included in the model because it is controversial to place a value or dollar amount on a human life.

3.2.2 Validated Model Assumptions

The assumptions of the model are truly the most important area for discussion because if an assumption is incorrect, the results will be misleading and invalid. In this subsection the principles of decision analysis are validated for this model.

Since this model has several 'costs' an explanation of the differences of each 'cost' is required. The Research, Development, Testing and Evaluation (RDTE) Cost is the only true expense related to the decision. The RDTE cost expresses the amount of money that

the Air Vehicles Directorate will spend on the technology to develop it to a technical readiness level (TRL) of six. A TRL equal to six implies that the technology has been demonstrated in a model or prototype environment. The TRL levels range from one to nine and were developed by the National Aeronautics and Space Administration (NASA) to explain the stages of a technology's development [Carter, 1997]. The other costs are project costs that are directly tied to the technology's application on a fixed wing vehicle. The development cost is the cost required to get the technology from a TRL of six to a TRL of nine. (A TRL equal to nine implies that the technology is actually "flight proven" through successful mission operations.) The production cost and operations and support cost are the projected costs of acquiring and using the fixed wing vehicle with the new technology onboard. They are also included in the model because they are important benefits of the proposed technology.

A debated issue of multiple objective analysis models is whether or not to include cost in the model or to use cost for a cost benefit analysis once the model has been created. The development, operations and support, and production cost should be included in the model, because they are not the traditional issues facing cost and are instead a result of the technology's application. Not including the RDTE cost in the model is similar to not including the price when deciding what type of car to purchase in the future. All four costs are independent and never double count the same dollar. For these reasons all four cost measures are included in the model. However, in chapter four the results are checked to see if they are the same using a cost benefit analysis approach was chosen.

A concern of the model is the existence of attribute independence between each of the evaluations measures. It can be shown that some of the evaluation measures are functional related; thus, it is not appropriate to include some of the technologies. However, from the laboratory's perspective, the evaluation measures are considered independent. An example of this independence is the fact that the controllable angle of attack can be increased without changing the lift or drag coefficients. Also, the take off gross weight (TOGW) can be increased without changing the empty weight of the aircraft. Some technologies will affect several evaluation measures, but the independence of the evaluation measures is not an issue.

The model has been checked to insure it is collectively exhaustive and mutually exclusive. This has been done by asking the people at the Air Vehicles Integration Division if two technologies were identical in all of the listed evaluation measures, whether there were any other reasons one technology is preferred over another technology. This question was used repeatedly to bring the model to its present state. Once there were no new aspects then the model was declared collectively exhaustive. It was then reviewed to insure that no attribute was double counted in the model. This insured that the attributes were mutually exclusive. Therefore, the model is both collectively exhaustive and mutually exclusive.

The model also includes the principles of operability and small size. The model is well understood by the decision maker. It is also in the terms and linguistics of the decision maker. These add to the models operability. Also the model attempts to use the most encompassing attributes to insure the smallest final hierarchy as possible.

On the basis of thorough discussions with the Air Vehicles Integration Division it has been assumed that the costs are all mutually preferentially independent. This assumption has been largely based on the laboratory view that all the evaluation measures are independent when comparing them on a similar airframe. If the airframe was to significantly change this assumption will no longer be valid. Therefore, while the assumption is valid if changing the avionics on two different F-117's, it may not be valid if comparing two different fixed wing aircraft, such as comparing the F-16 to the F-15. Nevertheless, all the evaluation measures are assumed to be preferentially independent in this model. The assumption of mutual preference independence can be tested by using a pair-wise comparison that reduces the total number of comparisons made [Kirkwood, 1997: 239]. This allows for the use of an additive value function to describe the model relations. This function is able to capture and weight all of the important aspects of the R&D investments decision.

If the technologies are compared on multiple platforms the decisions would need to be separated. However, the decision maker will recognize the performance of the technology when applied to the different platforms. This insight will enable the decision maker to further justify the technology based on the performance across multiple airframes.

3.3 Model Implementation

An automated Microsoft Excel 7.0 program was created to run the model. This program utilizes the visual basic programming capability of Microsoft Office 95. Because

the laboratory is constantly defending the selection of various technologies the automated program is user friendly to help provide insight to the relative values of the R&D of technologies. The automated program has five main components. The first two components allow the user to easily adjust the value functions and weights for each evaluation measure. The last three components provide the data analysis and two forms of sensitivity analysis.

Specifically, the first component allows the user to adjust the value function for each evaluation measure. The value function is assumed to be an exponential value function, as described in Appendix A. Since the exponential value function is used the model is limited to continuous functions with linear relations or smoothly changing relations. Also, the use of step functions for the value function are not allowed. The user provides the score with the most value and also the score with the least value and then adjusts the exponential curves by entering the score where 50% of the value is obtained or by actually entering the value for rho (ρ). The program provides the user a graph of the value function to insure that the value has been correctly modeled for each evaluation measure. If this graph is inconsistent with the user's value they are easily changed. An example screen shot of the program's evaluation measure's component is shown next (figure 3.3).

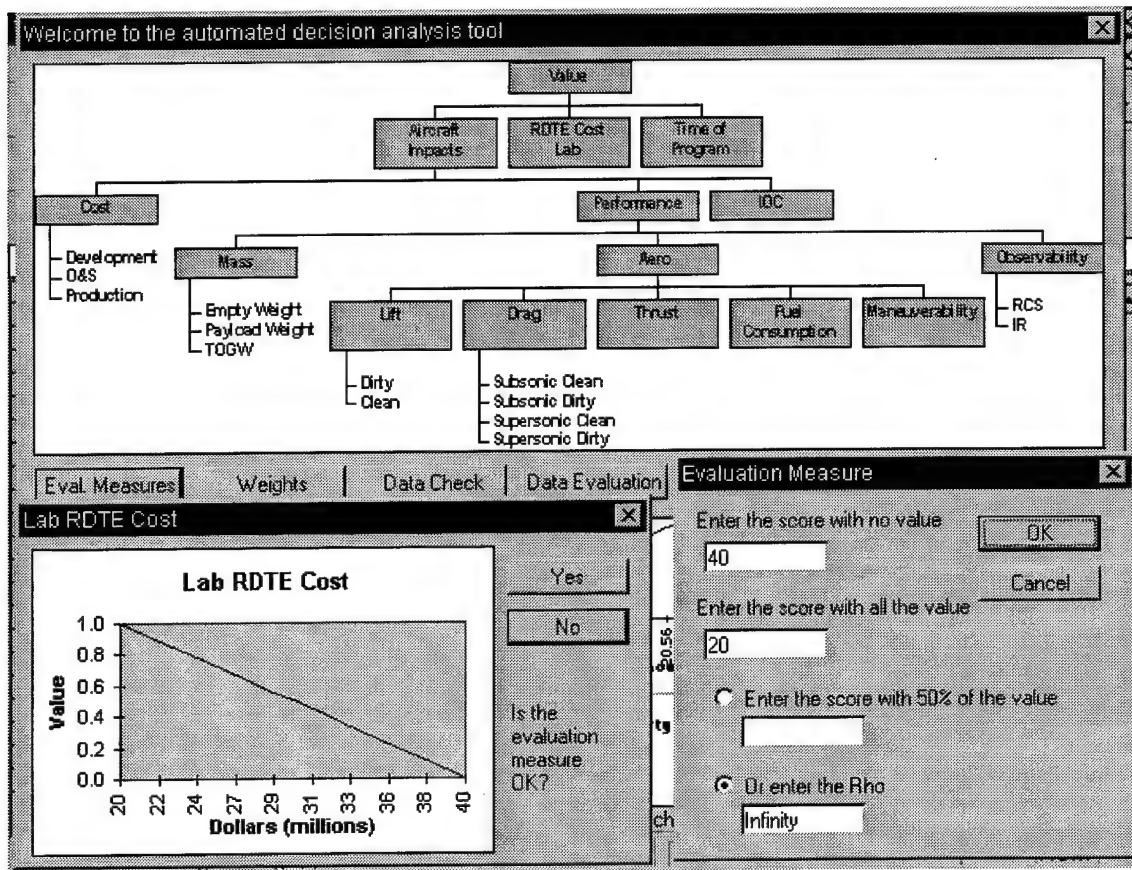


Figure 3.3 Screen shot of evaluation measure component

The second component allows the user to adjust the weights for each tier of the hierarchy (figure 3.4). The user is shown a pie chart for each tier and then prompted if it is correct. If the weights are incorrect for the current decision, the user is able to vary them to capture the proper decision structure. This component also has 'preset' personalities. These are predetermined weights that represent a particular mindset. The personalities include a person that weights aircraft performance highly, a person that considers what the lab is spending (both time and money) as very important, and a person that finds the total cost and time to the public is highly important. These three personalities cover the most common views on the decision. Another feature of this

component is to see the current setting of weights. This feature shows the total break-out of the weight for each evaluation measure. Also, the sum of all 20 evaluation measures should equal one.

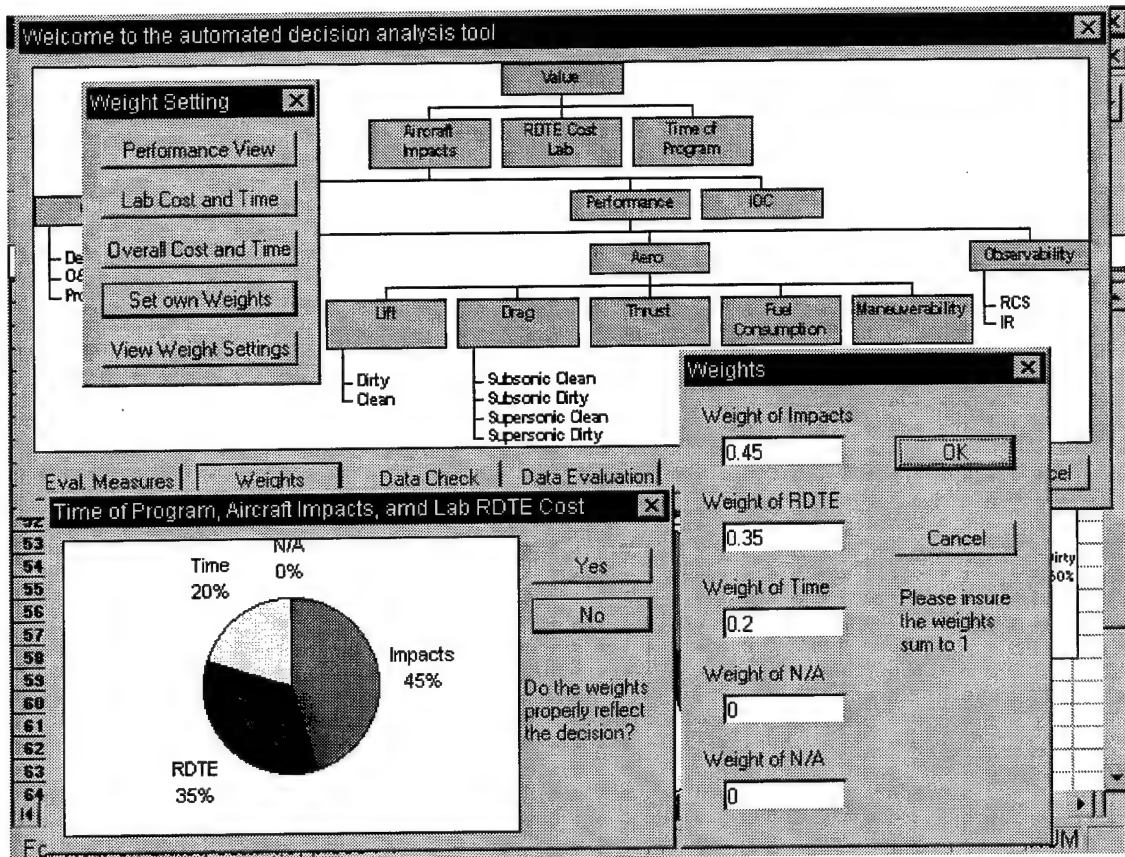


Figure 3.4 Screen shot of weight component

The third component provides the deterministic data analysis. It is provided in three forms. The first form is the total value for each technology shown in a bar chart. The second form is a bar chart for each technology color-coded to include all of the evaluation measures. This allows the user to see where the value for each technology comes from. The final form condenses the bar chart to only show the value from the main tiers. So only eight areas are shown as opposed to the 20 evaluation measures. This

allows the user to easily understand the important issues and the good/bad areas of each technology (figure 3.5).

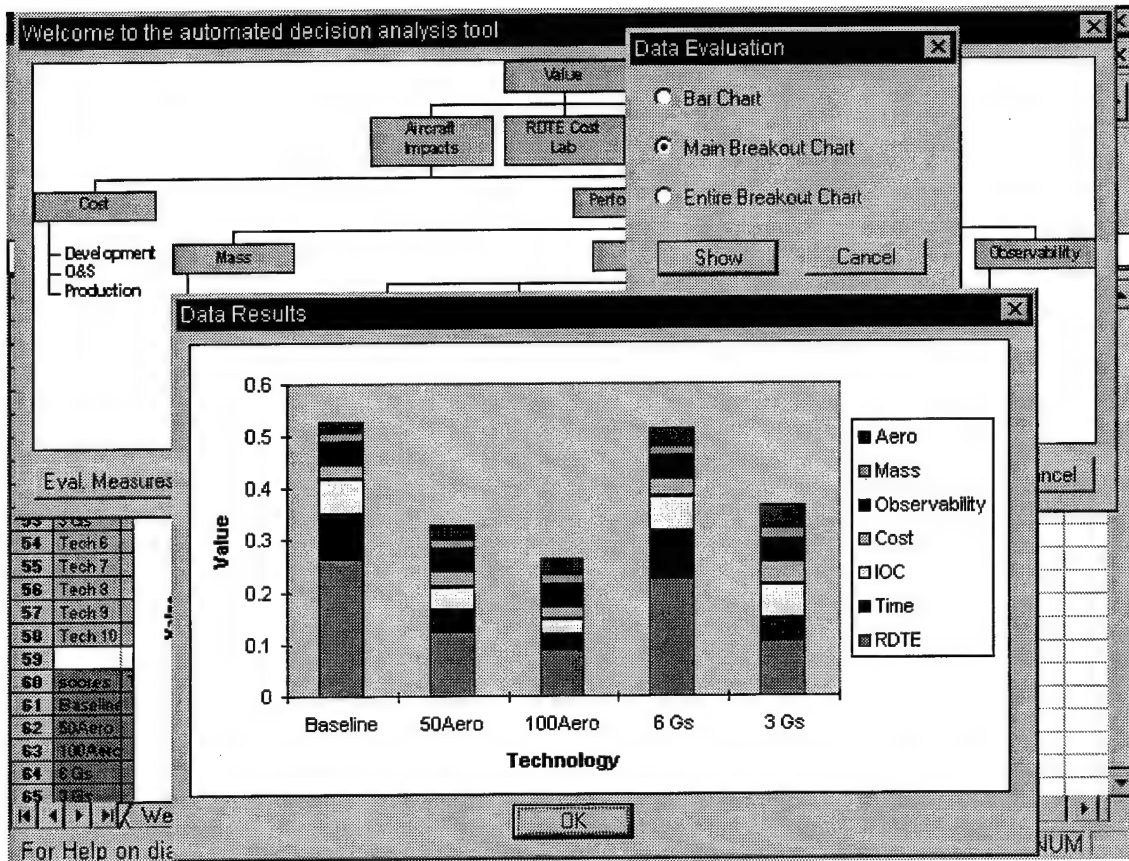


Figure 3.5 Screen shot of data evaluation component

The fourth component varies the weights for each evaluation measure. The user is prompted to select which evaluation measure's weight is to be varied from 0 % to 100%. This option is available for every evaluation measure. The result is shown to the user as a line graph with each technology listed (figure 3.6). The graph also shows what the current setting is for the weight. Thus, the decision maker can see how the decision will be affected by variability of that weight. If the decision is insensitive to the changes then the decision needs no further exploration in this area. If the decision is sensitive to the

change then more time may need to be spent to accurately assess the decision maker's values.

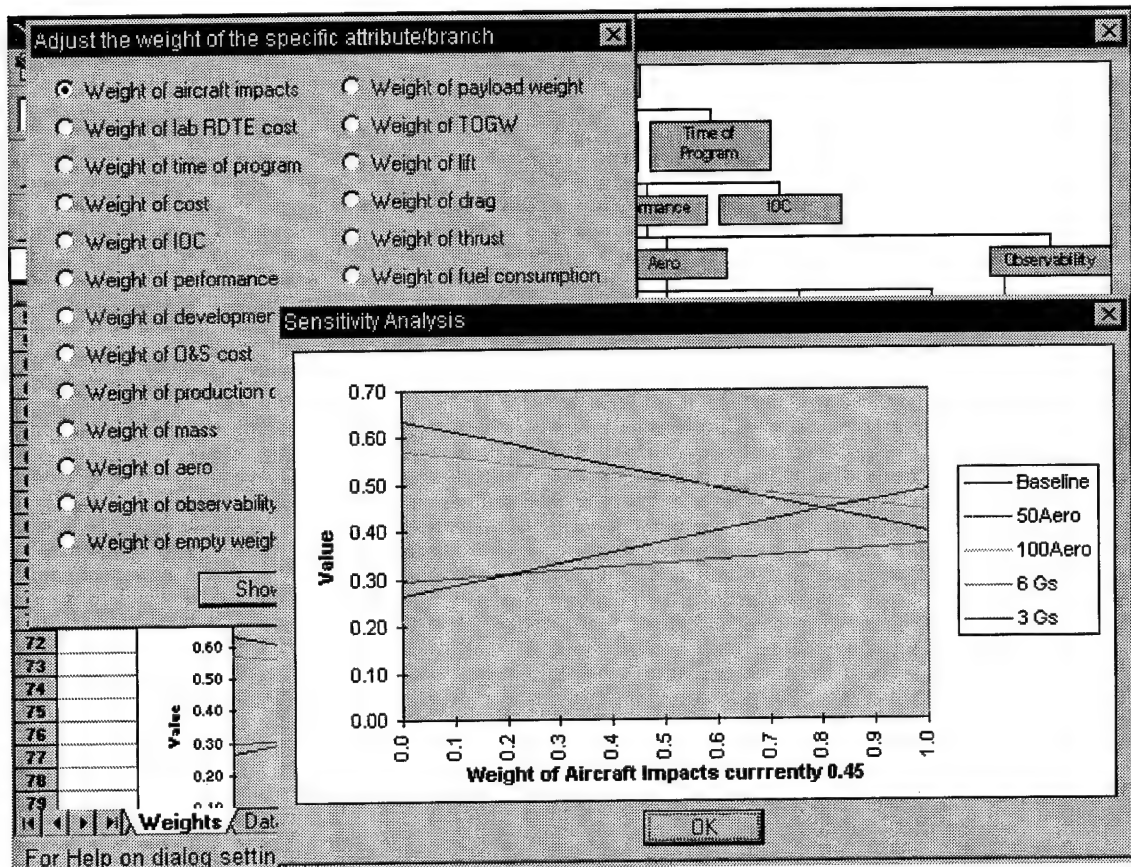


Figure 3.6 Screen shot of sensitivity analysis component

The fifth and final component of the automated analysis program incorporates uncertainty analysis. The decision maker is allowed to pick up to five evaluation measures that have uncertainty. The user needs to insure that the low, medium, and high data points for each uncertain measure are entered on the data worksheet. The data points correspond to the 5%, 50% and 95% fractiles that are used by the Pearson-Tukey approximation. After selecting the five or less uncertain measures, the computer returns a

CDF for the user to interpret (figure 3.7). The CDF is able to give the user important information about mean, variance, deterministic dominance, and stochastic dominance.

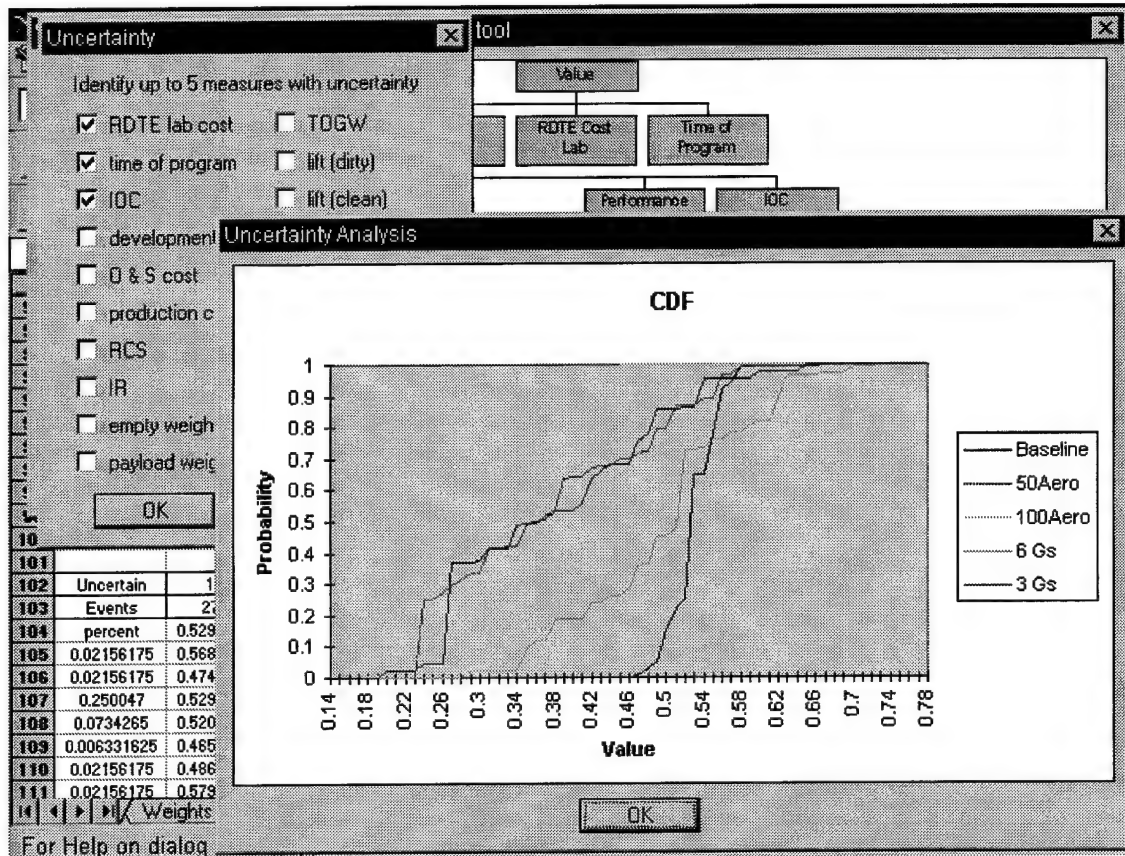


Figure 3.7 Screen shot of uncertainty analysis component

The limit of five evaluation measures was chosen because it takes a Pentium 133 computer 15 minutes to calculate the results for five measures. To include six evaluation measures the computer time increases to 45 minutes. If all 20 evaluation measures are included in the uncertainty analysis, theoretically it would take over 400 years to finish calculating. The computer requires this much time because of the visual displays being utilized by the program. For these reasons it is beneficial to limit the capability of the program. If more than five uncertain measures are checked off only the first five will be

used in the analysis. However, if the decision maker needs to include more uncertain evaluation measures the problem can be modeled in other tools specifically tailored for decision analysis. These other tools can use Monte Carlo simulation to include the uncertainty with minimal time.

The program has one other feature called data check. This simply tells the computer how many technologies are being compared. This is used to correctly scale all of the graphs that are used and also to limit computer compiling time. The program is currently setup to compare up to ten technologies.

All six components are accessed from the initial hierarchy dialog box. This dialog box is automatically started when Microsoft Excel opens the file. If the program is stopped while the file is still open, it can be restarted by going to the toolbar and selecting 'Tools' and then clicking on 'StartUp'. This shows the initial hierarchy dialog box and all components are then accessed from there. Listings of the program and functions that are called by the program are located in Appendix D.

3.4 Conclusion

To conclude this chapter, a value hierarchy has been developed to solve the investment problem facing the Air Vehicle Integration Division. This model incorporates an additive value function using a simplified computation of the total value obtained from each alternative based on important evaluation measures. An automated decision modeling program has been created to help the laboratory with future decisions. This tool is applied to an example decision in the next chapter.

4. Example

The fourth chapter is focused on providing and analyzing an example to further check the validity of the model. The analysis tool discussed in the previous chapter will be used in conjunction with CASDAT. Specifically, the analysis tool will provide insight to the output data from CASDAT. However, CASDAT is not yet fully operational so this example is based on a combination of real and fictional data. More importantly, this is only an example and is for illustrative purposes only.

The chapter is divided into two main sections. The first section provides the background to the example. It explains the various technologies that are being compared and also lists the important data for each technology. The second section is the analysis of the five different technologies and provides important conclusions that can be extracted from the data through the use of the decision analysis tool.

4.1 Example Background

The objective of this thesis is to create a model which accurately includes all of the important (from the decision maker's viewpoint) effects of a technology on a fixed wing aircraft. The theoretical basis of the model is sound but that does not imply that the model will produce meaningful results, thus an example, with predictable results, has been created to see if the model is appropriate. This example consists of creating an uninhabited strike aircraft as a baseline and then applying two different technologies to the aircraft. Each technology has two different levels of implementation. This creates a total

of five different technologies to compare. The uninhabited strike aircraft with no technological changes will be referred to as the 'baseline' technology.

The uninhabited strike aircraft was designed to perform a suppression of enemy air defenses (SEAD) mission. This is a mission where the aircraft is used to attack surface to air missiles (SAMs) and other targets which limit our ability to control the airspace of the battlefield. The strike aircraft will be similar in shape to the B-2 bomber but will be a much smaller aircraft (figure 4.1). The strike aircraft will not be capable of supersonic cruise, nor will it carry weapons externally. The main rationale for an aircraft of this type is to gain an early dominance of the airspace over the battlefield with minimal loss of aircrews and resources.

The two technologies that are being tested on the uninhabited strike aircraft are an aeroelastic wing and a lower structural integrity of the aircraft. The aeroelastic wing involves changing the shape of a wing in order to improve the aerodynamic capabilities of the aircraft during flight. This idea is based on the early aircraft that the Wright brothers flew which involved wing-warping. Thus, a wing that can change its shape during flight would be able to produce more lift during take-off then reduce the parasitic drag caused by a highly cambered wing during the cruise portion of flight. This is the first stage of the technology's development, referred to as '50% aero' because the technology is only at a 50% stage of maturity. The full maturation of the technology involves investing more time and money, and results in an aircraft with no control structures. Instead of the normal complement of flaps, ailerons, and elevators, the aircraft will change the shape of the wing to change direction and altitude. This is referred to as '100% aero'.

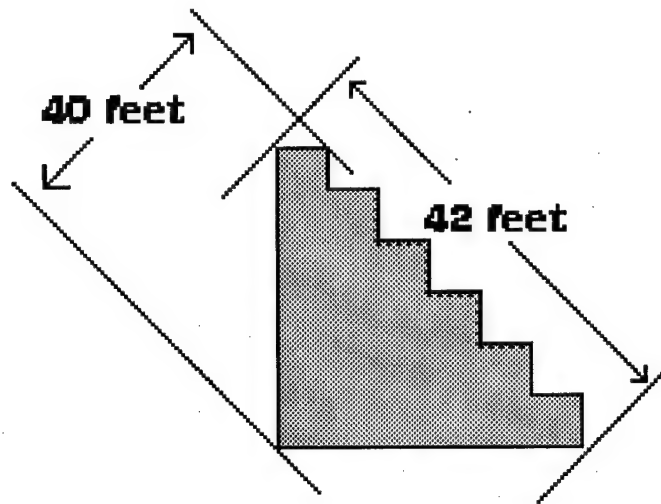


Figure 4.1 Uninhabited Strike Aircraft

The technology that changes the structural integrity on the aircraft results in the aircraft having a lower g-load capability. Normally fighter aircraft are designed to withstand approximately 9 Gs of stress. By reducing this, the resulting aircraft will be lighter, and thus able to carry heavier payloads and more fuel. The reduced integrity also results in a cheaper purchase price for the aircraft. In the following example there are two levels of integrity investigated. The first level is reducing the structural design limit to 6 Gs. This level has already been implemented on the F-117 stealth fighter. The second level is reducing the design g-load to 3 Gs. These levels are considered two different technologies and are referred to as '6 Gs' and '3 Gs' in the example.

Most of the data was supplied by the Air Vehicles Integration Division using a program known as FLOPS (Flight Optimization System) which is a component of CASDAT. FLOPS is able to provide aeronautical data, and mission performance data along with limited cost analysis data. The data that FLOPS could not provide was

generated through discussions with the client. The data was entered into the model and five areas of concern were indicated for uncertainty analysis. The data used in the model can be found in table 4.1.

Table 4.1 Model example data

Eval Meas \ Technology	Baseline	50% Aero	100% Aero	6 Gs	3 Gs
Lab RDTE Cost	25	33	35	27	34
Time of program	5	6.5	7	5	6.5
IOC	7	7.5	8	7	7
Development Cost	35	40	43	36	38
O&S Cost	2.5	2.4	2.4	2.4	2.3
Production Cost	12.5	12	12	11.5	11
RCS	0.333	0.25	0.2	0.333	0.333
IR	2	2	2	2	2
Empty Weight	12.4	12.3	12.1	12	11.7
Payload Weight	6	6	6	6	6
TOGW	20	21	22	19	18
Lift-Dirty	32.6	33.13	33.13	32.958	32.786
Lift-Clean	32.6	33.13	33.13	32.958	32.786
Drag-Subsonic-Clean	1.3	1.4	1.4	1.2	1.25
Drag-Subsonic-Dirty	1.3	1.4	1.4	1.2	1.25
Drag-Supersonic-Clean	N/A	N/A	N/A	N/A	N/A
Drag-Supersonic-Dirty	N/A	N/A	N/A	N/A	N/A
Thrust	18.73	18.73	18.73	18.73	18.73
Fuel Consumption	6.73	6.6	6.58	6.3	6.05
Maneuverability	30	33	35	29	25

The lift evaluation measures for clean and dirty are the same, because the aircraft does not have external weapons or fuel tanks. Similar to lift, drag will have the same results for clean and dirty flight. In addition, the aircraft does not exceed subsonic flight, thus there are no results for the supersonic drag. It was determined that the RDTE lab cost, time of program, IOC, empty weight and TOGW were all uncertain evaluation measures. The fractile values for the uncertain evaluation measures can be found in table 4.2

Table 4.2 Uncertainty data for model example

5% fractile	Baseline	50Aero	100Aero	6 Gs	3 Gs
Lab RDTE Cost	24	28	33	25	28
Time of Program	4.5	3	4.5	3	3.5
IOC	6.5	6.5	6.5	6	6.25
Empty Weight	12.45	12.35	12.15	12.05	11.8
TOGW	21	23	23	20.5	20
50% fractile					
Lab RDTE Cost	25	33	35	27	34
Time of Program	5	6.5	7	5	6.5
IOC	7	7.5	8	7	7
Empty Weight	12.4	12.3	12.1	12	11.7
TOGW	20	21	22	19	18
95% fractile					
Lab RDTE Cost	25.5	34.5	37	32.5	38
Time of Program	6	8	8.5	8	8.5
IOC	7.5	9.5	10	9.5	9.5
Empty Weight	12.35	12.25	12.05	11.7	11.6
TOGW	19	20	21	17.5	16

The evaluation measure value functions are assumed to be exponential. The following value function is the Time of Program evaluation measure (figure 4.2). The figure represents diminishing returns to the laboratory, because the ρ equals -3. This is only one of twenty evaluation measures. The value function for each evaluation measure is listed in Appendix C. This appendix also gives the high and low level for each value function and also the value for ρ .

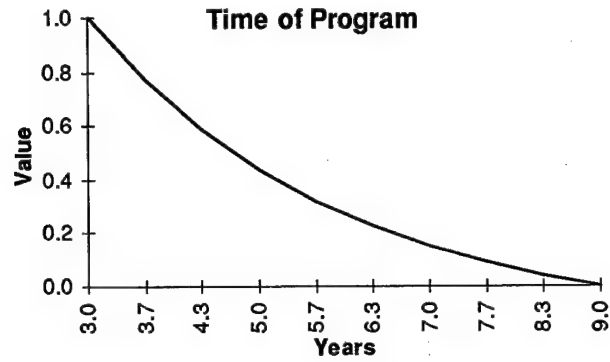


Figure 4.2 Value Function of Time of Program

In chapter 3 the additive value function for this example was shown. This function included the final weight settings for the decision. They are again listed in table 4.3 along with the weights of the evaluation measures at each tier. This was all provided by the client and used in the following example.

Table 4.3 Weights used in the example

Tier	Event	Tier Weight	Final Weight
First Tier	Aircraft Impacts	0.45	
	RDTE Cost	0.35	0.3500
	Time of Program	0.20	0.2000
Aircraft Impacts Tier	Cost	0.20	
	IOC	0.30	0.1350
	Performance	0.50	
Cost Tier	Develop	0.30	0.0270
	O&S	0.30	0.0270
	Production	0.40	0.0360
Performance Tier	Mass	0.20	
	Aero	0.40	
	Observability	0.40	
Mass Tier	Empty Weight	0.40	0.0180
	Payload	0.40	0.0180
	TOGW	0.20	0.0090
Aero Tier	Lift	0.10	
	Drag	0.15	
	Thrust	0.15	0.0135
	Fuel Consumption	0.30	0.0270
	Maneuverability	0.30	0.0270
Observability Tier	RCS	0.60	0.0540
	IR	0.40	0.0360
Lift Tier	Dirty	0.60	0.0054
	Clean	0.40	0.0036
Drag Tier	Sub-Clean	0.15	0.0020
	Sub-Dirty	0.30	0.0041
	Super-Clean	0.20	0.0027
	Super-Dirty	0.35	0.0047

Since there are twenty evaluation measures, the additive value function is a sum of the values multiplied by the weights for the twenty different evaluation measures. These evaluation measures are defined in appendix B. For the example the additive value function is,

$$\begin{aligned}
 \text{Value} = & 0.35 * V_{\text{RDTE}} + 0.2 * V_{\text{time}} + 0.135 * V_{\text{IOC}} + 0.027 * V_{\text{develop}} + 0.027 * V_{\text{product}} \\
 & + 0.036 * V_{\text{O\&S}} + 0.054 * V_{\text{RCS}} + 0.036 * V_{\text{IR}} + 0.018 * V_{\text{EW}} + 0.018 * V_{\text{Payload}}
 \end{aligned}$$

$$\begin{aligned}
&+0.009*V_{\text{TOGW}} +0.0054*V_{L(D)} +0.0036*V_{L(C)} +0.002*V_{D(\text{Sub-C})} \\
&+0.0041*V_{D(\text{Sub-D})} +0.0027*V_{D(\text{Super-C})} +0.0047*V_{D(\text{Super-D})} +0.0135*V_{\text{thrust}} \\
&+0.027*V_{\text{fuel}} +0.027*V_{\text{maneuver}}.
\end{aligned}$$

It is important to note that the weights of some evaluation measures dealing with the aerodynamics of the air vehicle do not have a large impact on the model; however, the total sum of the weight for Aircraft Impacts is 0.45 and the total sum of weights for Performance is 0.225. Since, the decision maker does not weight these items highly in the model, the lower tiers will show less affect on the model.

4.2 Example

Once all the information has been input into the model, the model can begin to provide insight to the decision maker. Initially, the decision maker cares about the technology that has the most value, and where that value comes from. The bar chart in figure 4.3 shows that the baseline technology has the most value. This is because the aeroelastic wing and structure technologies do not obtain as much value from the aircraft impacts as is lost from RDTE cost and time of program. Thus, the best decision is to use the baseline case. There are other important issues that can be interpreted from the figure. First, the 50% aero and 6 Gs are both better than their more expensive and fully matured counterparts. Also, the 6 Gs technology and baseline appear to be close in value; however, the baseline does have more value. Since some of the evaluation measures are uncertain, the decision may actually change under different but possible conditions. Finally, it appears that the time of program and RDTE lab cost are the driving forces to the decision maker.

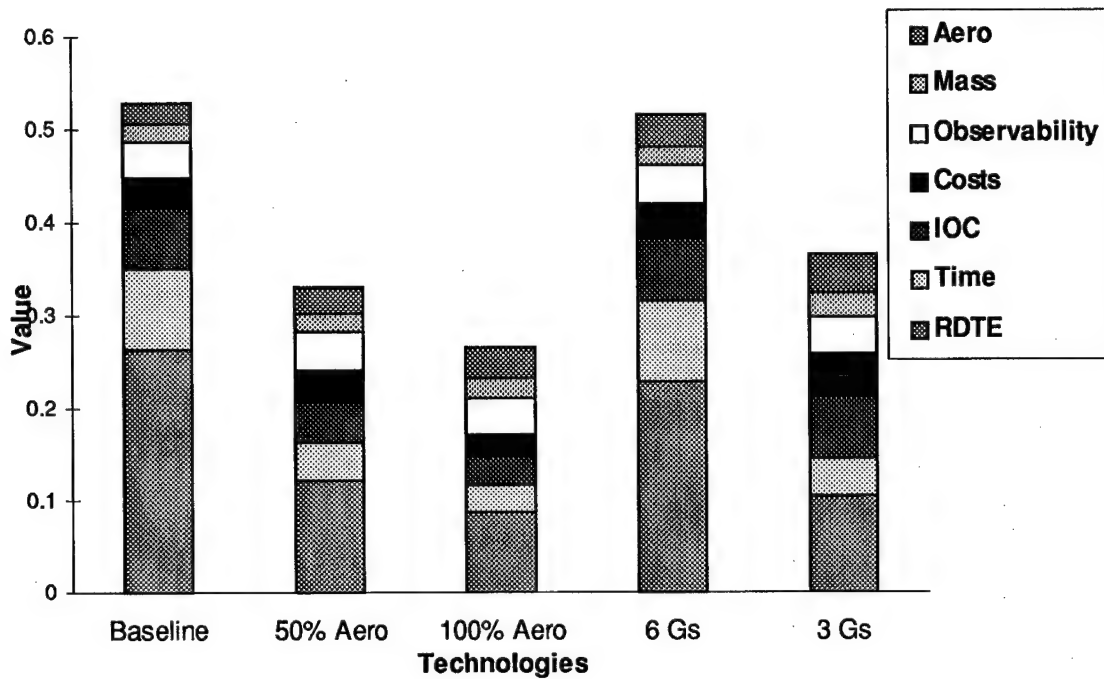


Figure 4.3 Total value for each technology

The benefit without cost is found by not including the laboratory RDTE cost in the total value. By dividing the benefit by the recently removed RDTE cost, a cost benefit analysis is performed (Figure 4.4). This figure shows the decision does not change from the conclusion drawn from figure 4.3; therefore, the two methods are equivalent. Since they produce the same ordering of technologies, including the cost in the hierarchy does not invalidate the model.

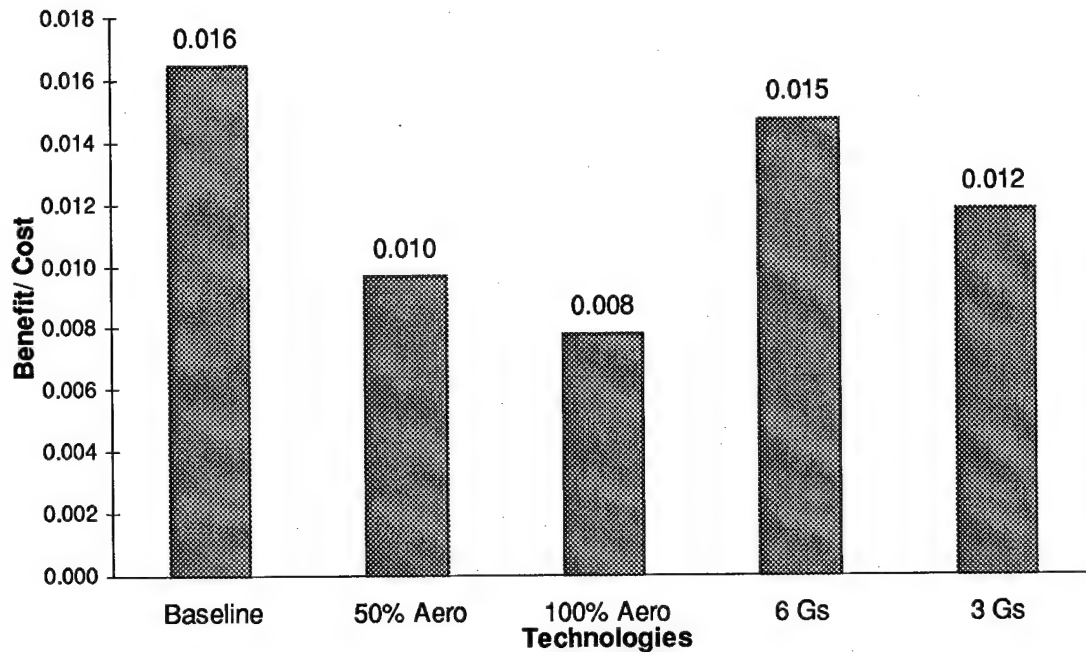


Figure 4.4 Cost Benefit analysis for example

The next step of the analysis procedure would be to investigate the sensitivity of the decision to changes in the objective weights. Figure 4.3 shows that the four new technologies have better aircraft impacts values than the baseline. Would the decision change if the weight of the aircraft impacts was varied from 0% to 100%? The answer can be seen in figure 4.5. The vertical line shows the current weight for Aircraft Impacts which is 45%. If the decision maker feels the weight may be more than 55% then there is a decision change to the 6 Gs technology. Since this is a little change, further investigation may provide useful insight. This is important because it appears the decision may be limited to selecting the baseline or 6 Gs technology. There is another change at 85% but this is unlikely given the current attitude of the decision maker. It is also interesting to notice that the 100% aero technology is consistently the worst technology.

This is not yet a dominance issue; however, it does indicate that the technology may not be the best solution.

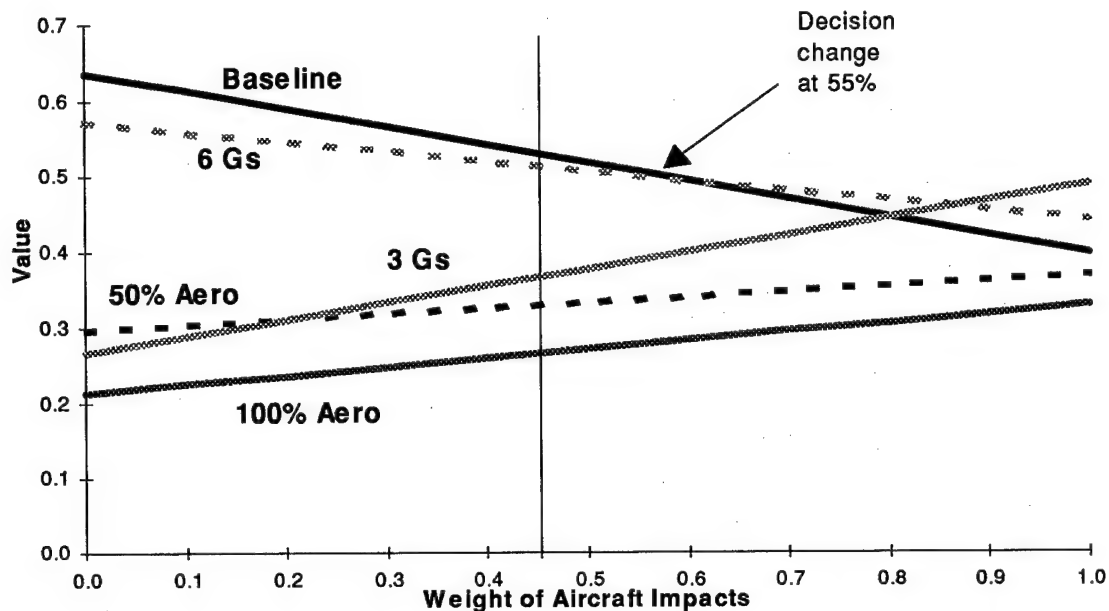


Figure 4.5 Impact from changing the weight of aircraft impacts

After testing the sensitivity of the decision, by varying all of the weights of the evaluation measures, it was concluded that the only weights that affected the decision were time of program, RDTE cost, and aircraft performance. Changing the other evaluation measure weights did not change the decision. Figure 4.6 shows how the weight for performance affects the decision and also represents how changing the weight on a lower tier does not affect the decision. The result from the varying of the weight of performance is typical of all the lower tier weights. Thus, the decision is insensitive to the lower tiers, because the decision does not change when the weights associated with the lower tiers change. Therefore, we can see that the first tier is the only tier that is sensitive to the weights from the decision maker in this example.

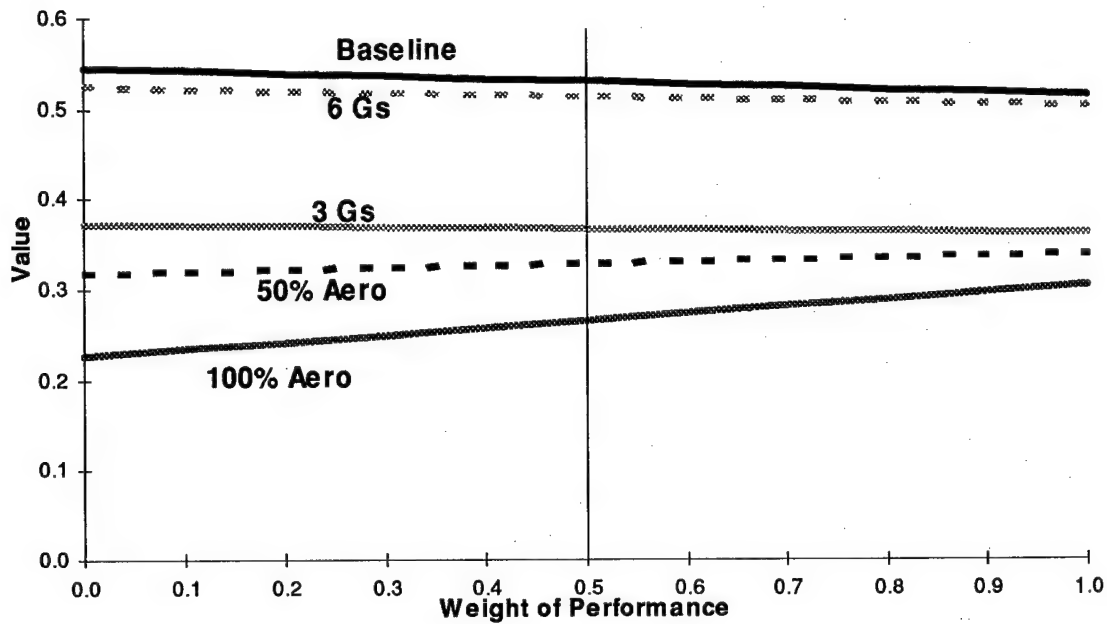


Figure 4.6 Impact from changing the weight of performance

The final step of the analysis is incorporating uncertainty. This is done by using the Pearson-Tukey approximation, which discretely approximates the probability using three fractiles. Since there are 5 different uncertain evaluation measures with three levels each used in the approximation, there are a total of 243 discrete events. Figure 4.7 shows the resulting cumulative probability distribution (CDF) for the value of each technology.

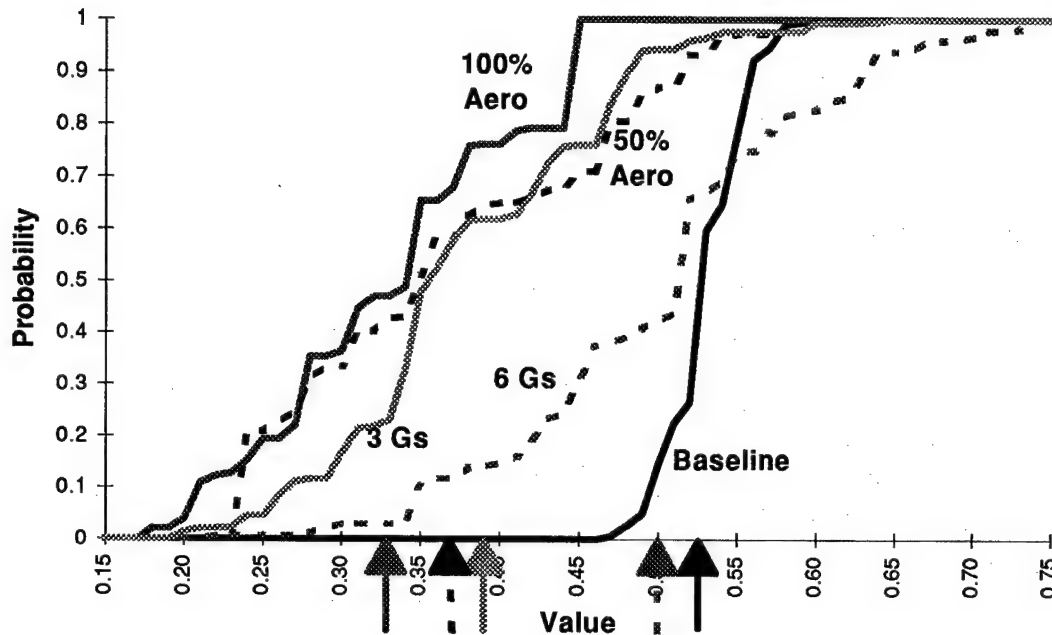


Figure 4.7 CDF for each technology

This CDF is able to provide several important characteristics of the technologies. The variance in the technologies is found by calculating the slope of the line, where a steeper slope means less variance. Also, upon inspection of the figure, it can be seen that the 6 Gs technology is able to get more value than any other technology; however, there is only a 25% probability of this. There is an 75% probability that the baseline case is as good or better than the 6 Gs technology. It is also apparent the aeroelastic technologies and the 3 Gs technology all are closer in their variance and expected value. Table 4.4 shows the expected values for each technology which is found from the CDF and is indicated on figure 4.7 by the color-coordinated arrows.

The decision between the baseline and 6 Gs technology depends on the risk tolerance of the decision maker. This is because the baseline technology has less variance

in its value, whereas the 6 Gs technology is able to do very well but it can also do poorly. Thus, a risk seeking individual may prefer to pick the 6 Gs technology since there is a chance of getting more value for the investment. On the other hand, a more conservative individual may choose to use the baseline technology since its value has less variance.

It is also important to see that the 6 Gs technology has more value than the other technologies on the CDF. This is because the 6 Gs technology stochastically dominates all of the other technologies except the baseline technology. The stochastic dominance is present because the 6 Gs line is always to the right of the other three technologies. The main point of this stochastic dominance is that the 3 Gs technology is not going to be a better decision than the 6 Gs technology. Also, the 6 Gs technology is better than the aeroelastic technologies because of the stochastic dominance.

Figure 4.7 also shows that the 100% aero technology can be removed from further analysis, because there is deterministic dominance between the baseline technology and the 100% aero technology. This dominance means the value for the baseline case, under its worst case scenario, is still better than the 100% aero technology at its best case scenario. The figure illustrates this because there is a 100% probability that the 100% aero technology will achieve a value of 0.47 or less, and the baseline technology has 0% probability of obtaining a value of 0.47 or less. This is important to the decision maker because the 100% aero technology is never a better decision than the baseline technology.

Table 4.4 shows the expected value for the baseline is better than the expected value for the 6 G's. The expected values, from table 4.4, are not the same as the values

from figure 4.3. The difference in the results is because table 4.4 includes all of the probabilities from the CDF.

Table 4.4 Expected value from the uncertainty analysis

Technology	E(V)
Baseline	0.530
50% Aero	0.363
100% Aero	0.329
6 G's	0.500
3 G's	0.378

4.3 Conclusion

It appears the best decision is to not apply the technologies to the current version of the uninhabited strike aircraft. The only exemption to this is to possibly investigate further into the reducing the structure of the aircraft. It may prove to be more beneficial to design the structure of the aircraft at some g-level between the current 9 Gs and proposed 6 Gs. More importantly the aeroelastic technologies should not be included on this airframe.

When these results were presented to the Air Vehicles Integration Division, many of the conclusions were verified by current instincts of the type of aircraft that the technologies were being compared on. First, the aeroelastic technologies are not expected to perform well on an aircraft with a large delta wing. It is also expected that the as the aeroelastic technology is applied to the aircraft the value of the technology will decrease. This can be directly seen in all of the various analysis done on the alternatives in this research. Secondly, since this aircraft is very similar to the F-117 it is not surprising that

the ideal structural design would be similar. The F-117 is currently designed to withstand 6 Gs. This uninhabited Strike aircraft does tend to show more value from having less than 9 Gs but more than 6 Gs. Since the model does incorporate the common perceptions of how the vehicle should be designed it is verified to accurately model the decision.

5. Conclusions

5.1 Summary

The problem facing the Air Vehicles Integration Division centers on how to best allocate resources for technology development. The idea is to fund technologies that provide the most benefit to the Air Force. The laboratory has been directed to accomplish various objectives listed in their TDA; however, these objectives do not fully represent all of the capabilities of each technology. Therefore, the hierarchy that was developed includes the original objectives but it also includes many other important aspects of aircraft design.

After the model was designed it needed to be validated and implemented. The model was checked to insure all of the important principles of decision analysis were not violated. Then this validated model was implemented on a spreadsheet. The spreadsheet model was designed to be very user friendly. By creating an automated decision tool the decision maker is able to test various technologies with minimal effort. Once the analysis has been performed the figures can be transferred to other applications for justification during later stages of the decision process.

Once the model was implemented on a spreadsheet it was tested for accuracy. By creating a realistic example the model was tested to see if it produces logical results. The example that was tested had predictable results. The results for the model mirrored the expected results. This implies that the model does accurately portray the decision making

issues that the laboratory faces. Finally, since the model does accurately represent the important issues that face the decision maker, it can provide useful insight.

5.2 Recommendations and Future Research

The next step in this research should be to use the automated decision tool on a real world technology decision. The decision should not be solely based on the results from the model, but the model should provide insight to the decision maker.

The most important area for future research is to check the assumption of mutual preferential independence. This assumption can be specifically tested by using pair-wise comparisons between each combination of evaluation measures. This is difficult as well as time consuming and thus not performed in this thesis; however, it does provide a solid defense to the assumption. Currently, mutual preference independence has been assumed based on the laboratory's opinion that the evaluation measures are independent so long as the airframe does not change. Through a formal investigation in this matter it may be concluded that this assumption is too narrow and that the technologies can be compared on different airframes. It may also be concluded that the simple airframe assumption is incorrect and more restrictions are required to have mutual preference independence.

The next area that would benefit from further research is to use utility instead of value for the evaluation measures. This step would allow the risk tolerance of the laboratory to be input to the model. The addition of risk tolerance simplifies the uncertainty analysis by incorporating the risk personality of the laboratory in the model.

Another area that requires more work is adding the value of human life into the model. This is a very debated issue since a dollar amount can not be placed on a human life and that value of human life is just as difficult. The issue is important because various technologies will require one, two, or even three personnel on the aircraft. As the number of people on the aircraft increases, the loss of that aircraft becomes more devastating. The most difficult aspect to capture in the model is comparing an uninhabited aircraft to a piloted aircraft. Currently the model does not address this issue; thus, research is required to be able to tackle this shortcoming.

The model could improve by including a portfolio optimization routine. This would allow the laboratory, through the selection of various technologies, to obtain the best combination of attributes. Certain technologies will excel in different areas. Thus funding the technologies in such a way that different aspects are exploited a better use of the resources is obtained.

The final area that could use improvement would be to include the value that is obtained by various byproducts that the research creates. Possible byproducts are new technologies applied in different fields. It is also possible to spend less time and money on similar future technologies. To conclude, these improvements to the model will help provide more insight to the decision maker but if they are not included, the decision maker needs to be aware of these additional areas of concern.

Appendix A

Example of Multiple Objective Decision Analysis

The following example is adapted from Making Hard Decisions by Robert T. Clemen pages 535 to 552. This example has been altered to better illustrate the issues facing the Air Force Research Laboratory, Air Vehicles Integration Division.

Assume we need to buy a car and there are only three cars available for the decision. The three cars are known as Standard, Norushi, and Portalo. Initially the decision maker states the most important factors in buying a car are cost and life span. Cost is defined as purchase price and life span is defined to be time until the car is no longer a reliable source of transportation. Through research the following data (table A.1) was collected and is considered certain:

Table A.1 Initial car performance data

Model	Cost (\$1000)	Life Span (years)
Standard	8	6
Norushi	10	9
Portalo	17	12

These data points can be plotted on a comparison chart (figure A.1). This comparison chart displays the region which is most ideal since for less money, the life span is longer; however, no cars are in this region. Thus, a selection must be made which will trade-off increased cost for increased life span. Multiple objective decision analysis will be employed to understand this trade-off.

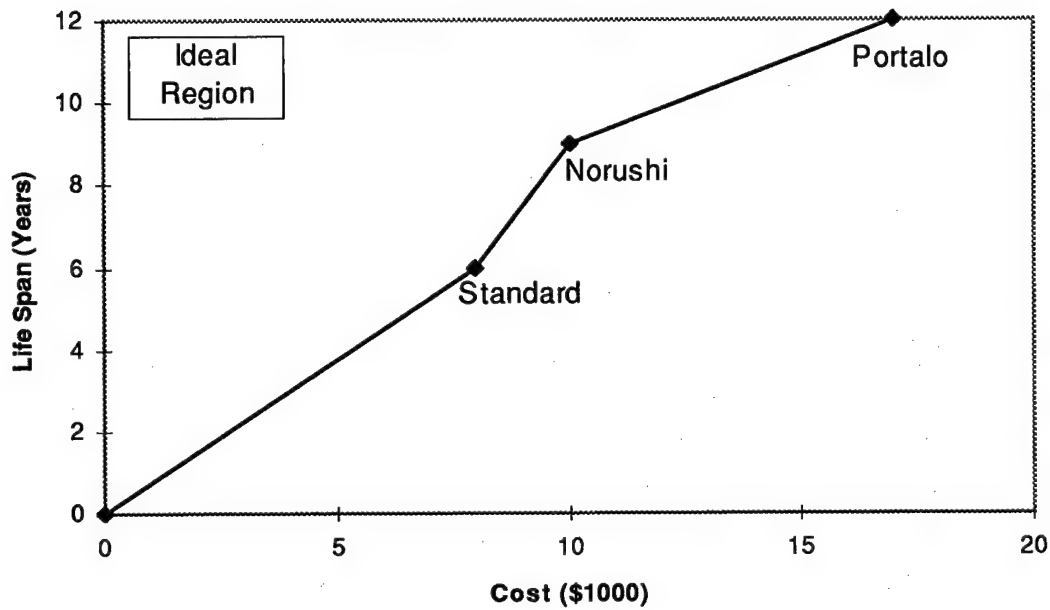


Figure A.1 Comparison of car data

The basic organization of the decision can be broken down into the value obtained from the cost and also the value from the life span. Thus, cost and life span are considered to be evaluation measures. This can be seen in figure A.2.

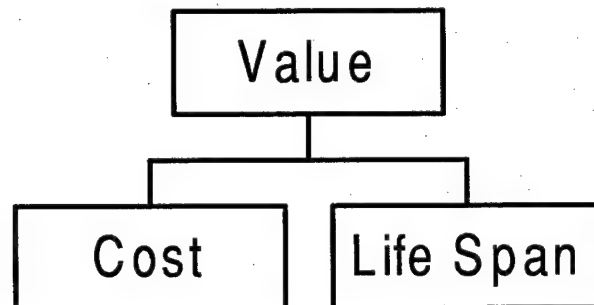


Figure A.2 Initial value hierarchy

For each evaluation measure there is an equation which relates the measure to a value for this decision. The evaluation measures are seen in the following charts (figures A.3-4).

The better the performance measure, the closer to getting '1' for the value. The undesirable levels will get a value of '0'. It is common to use an exponential function to capture the value function. The formula to do this for an increasing function (higher amounts of x are preferred) is (Kirkwood, 1997: 65),

$$v(x) = \begin{cases} \frac{1 - \exp[-(x - Low) / \rho]}{1 - \exp[-(High - Low) / \rho]} & \rho \neq \infty \\ \frac{x - Low}{High - Low} & otherwise \end{cases}$$

If the function is decreasing, in other words lower amounts of x are preferred then the formula is (Kirkwood, 1997: 66),

$$v(x) = \begin{cases} \frac{1 - \exp[-(High - x) / \rho]}{1 - \exp[-(High - Low) / \rho]} & \rho \neq \infty \\ \frac{High - x}{High - Low} & otherwise \end{cases}$$

For each function the 'High' is the highest level of x that is important to the client and 'Low' is the lowest level of x which is important to the client (Kirkwood, 1997:66). If the ρ is equal to infinity (or negative infinity) then the value function is exactly linear (figure A.3); however if the ρ is greater than ten (or less than negative ten) it is generally linear. The decreasing payoff as seen in figure A.4 is from a ρ that is about 3. The most common way to obtain the value for ρ is to find midvalue for the range. This is the level that obtains 50% of the value to the client. Using the midvalue and tables provided by Kirkwood, a ρ is able to be found.

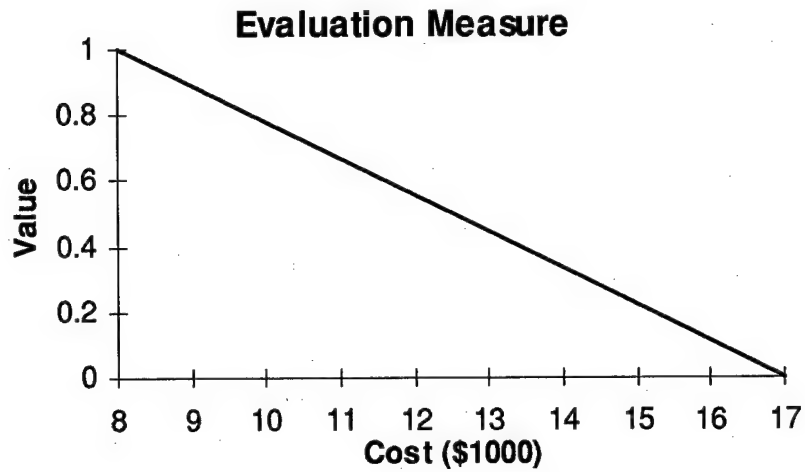


Figure A.3 Cost EM function

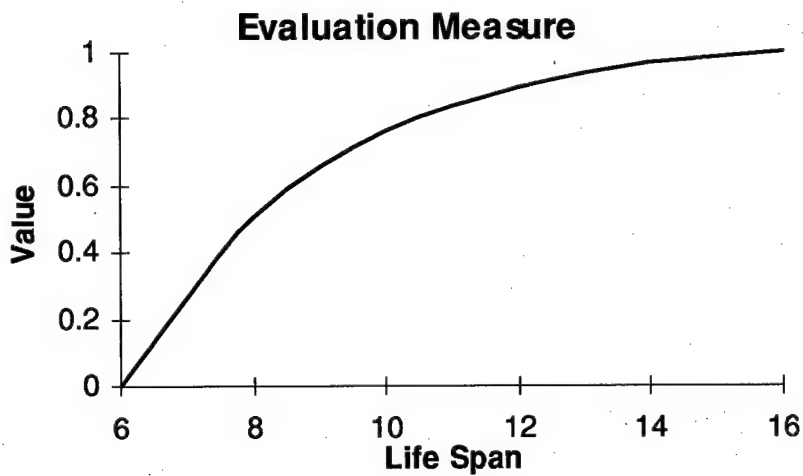


Figure A.4 Life Span EM function

By finding the value for each model of car we obtain table A.2, which illustrates the importance of the cost and life span to the decision maker and allows for some understanding of the tradeoffs.

Table A.2 Value from Evaluation Measures

Model	Cost	C Value	Life Span	LS Value
Standard	8	1	6	0
Norushi	10	0.778	9	0.656
Portalo	17	0	12	0.897

Next, we create an additive value function. The additive value function ties the two evaluation measures together. This involves obtaining a measure of the relative importance of the two different evaluation measures. For this example their importance to the decision maker is equal; therefore, the weight associated with each evaluation measure equals 0.5 or 50%. The additive value function for this example is,

$$\text{Total Value} = w_{\text{cost}} * V_{\text{cost}} + w_{\text{life span}} * V_{\text{life span}}$$

where w_i is the weight of the evaluation measure and V_i is the value for the evaluation measure. Since the weights are equal, the equation reduces to:

$$\text{Total Value} = 0.5 * V_{\text{cost}} + 0.5 * V_{\text{life span}}$$

Because we have the values for each car in table A.2 we are able to ascertain the total value for each car (table A.3). The best choice is the car with the value closest to '1'. In this example, the Norushi would be the better choice. This is not to be interpreted as meaning the Norushi is 50% better than the Portalo, since the value is a number that is 50% larger. The correct interpretation is simply the Norushi has more value to the decision maker than the Portalo.

Table A.3 Total value

Model	Value
Standard	0.50
Norushi	0.72
Portalo	0.45

At this point, the decision maker may decide that miles per gallon (MPG) also has an affect on the decision. By adding MPG to the model (figure A.5) we now have three evaluation measures and the weight must now be divided between the three. Suppose the decision maker finds that importance of MPG is worth half of the decision criteria and the other evaluation measures remain of equal importance. This would indicate that MPG receives 0.5 of the weight and cost and life span each receive 0.25 for their weights. The model will need to be resolved for this new model and again the best decision will be the alternative with the most value.

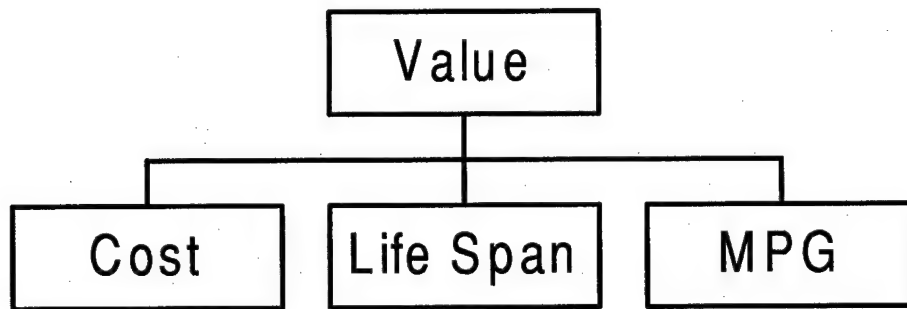


Figure A.5 Total value

Sensitivity analysis from a decision analysis model can provide a good deal of insight to the problem. A common way to perform sensitivity analysis is to vary the weight of the evaluation measures to see at what point the decision is changed. This can be seen in figure A.6. Here the decision is changed from Standard to Norushi if the

weight for MPG is below 0.25. The decision maker is faced with the question of whether the weight for MPG (currently at 0.5) might really be below 0.25. If this is not a possibility, then Standard is a good choice. If the weight can vary to below 0.25 then the decision maker may need to spend more time on clarifying their goals and determining their importance. This assumption specifically addresses if the assumptions of the weights are correct and if not when it matters.

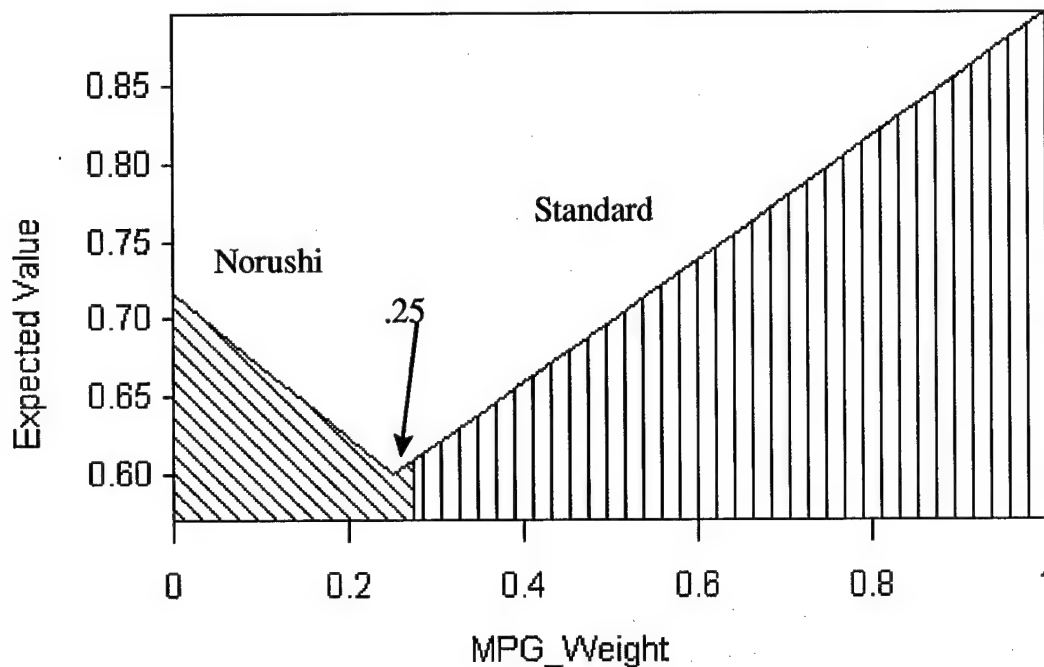


Figure A.6 Sensitivity of varying weight of miles per gallon

Another important area of sensitivity analysis is incorporating the uncertain data. If the decision maker can state the probability for an event to happen or understands the standard deviation of the measure, then uncertainty analysis can be performed. Suppose, for example, that the MPG data the manufactures state are not completely reliable. Figure A.7 shows an example of a cumulative density function (CDF) for such a situation. This figure is able to show many aspects of how to interpret and understand the importance of

the conclusions that uncertainty analysis can provide. First, the point labeled 'A' is read as, "there is a 40% chance that the Standard car will have a value of 0.32 or less." Also, the point labeled 'B' is interpreted as, "there is a 90% chance that Norushi will have a value of 0.49 or less." An important conclusion to be made is that Standard is a riskier alternative than both Norushi and Portalo. This is because Standard can have less value and also more value than Norushi and Portalo. From merely an expected value point of view the Standard is a better decision; however, it has more risk. The risk tolerance of the individual is helpful in deciding which is a better decision. Is the individual willing to pick an alternative with more risk and possibly more value, than an alternative with less variation in its value.

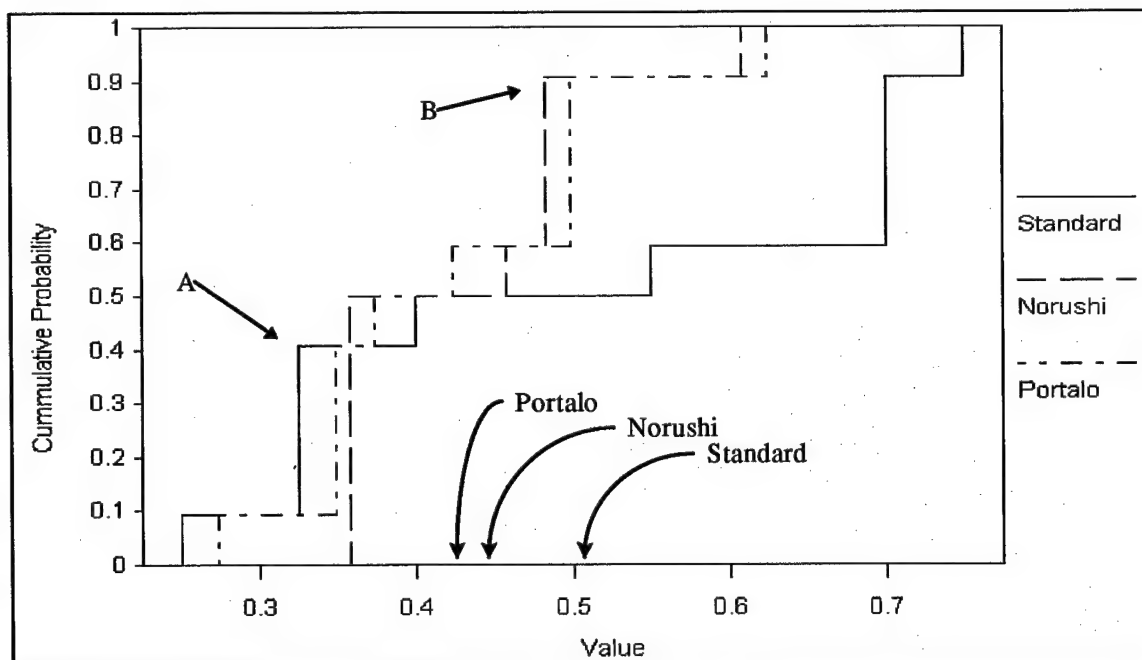


Figure A.7 CDF for car decision

This example has no dominance of any type. This is seen because the standard car can have more value than any other car but it can also have less value. Standard can not be

a dominating alternative nor can it be a dominated alternative. Similarly, the Portalo can have less value than Norushi but it can also have more value than Norushi. Therefore, Portalo is not dominated. For these reasons figure A.7 does not contain any dominance information.

The reasons to use multiple objective decision analysis in this manner are three fold. First, the tool of decision analysis is easy to understand and the analyst is not relying on magic black-box analysis. Second, the results are easy to justify and no random numbers are being used; thus, the answer is repeatable (i.e. simulation is not utilized for a one time decision). Finally, if the assumptions are challenged the model can be adjusted to incorporate the new view and then re-analyzed to see if the final decision is altered.

Appendix B

Definition of Evaluation Measures

RDTE Cost Lab: Research, Development, Testing and Evaluation Cost to the laboratory.

In other words, the total cost for the technology's development spent by the Air Vehicles Directorate in current year dollars to get the technology to a Technical Readiness Level (TRL) of six.

Time of Program: The total time, in years, the Air Vehicles Directorate spends to get a technology to a TRL of six.

Aircraft Impacts: The impacts of the new technology on the proposed fixed wing vehicle.

IOC: Initial Operating Capability, is the time, in years, to get the technology's TRL from six to nine. This implies the time from when the technology is proven in the laboratory until the time that that technology is on an fixed wing vehicle with an operations capability.

Cost: The costs of the aircraft with the new technology.

Development Cost: The cost in current year dollars to get the technology from a TRL of six to a TRL of nine on the chosen fixed wing vehicle.

Operation and Support Cost: The annual expected cost of the fixed wing vehicle in squadron service, in current year dollars.

Production Cost: The cost, in current year dollars, to acquire the fixed wing aircraft with the new technology.

Performance: This encompasses the results from the new technology applied to the fixed wing aircraft.

Mass: The aspects of mass of the fixed wing vehicle with the new technology

Empty Weight: The empty weight of the aircraft with the new technology. The empty weight is defined as the weight of the aircraft with no fuel, armament, or crew; however, the empty fuel tanks, radar systems, and other equipment is included.

Payload Weight: The weight of the payload of the fixed wing vehicle. This includes all ammunition, missiles, and bombs.

TOGW: Take Off Gross Weight of the fixed wing aircraft with the new technology.

Aerodynamics: These are the aspects of aerodynamics of the fixed wing vehicle with the new technology.

Lift: This combines all the important lift characteristics.

Lift (dirty): The ingress cruise lift. All weapons and drop tanks are attached. An appropriate altitude is picked for all technologies.

Lift (clean): The lift generated of the aircraft with no weapons, pylons, or drop tanks. This is 'cleaner' than the egress portion of the mission.

Drag: This is the drag for the fixed wing aircraft.

Drag Subsonic (clean): Drag from the aircraft at a subsonic cruise with no external carriage. This is taken at the same time as lift (clean).

Drag Subsonic (dirty): Drag from the aircraft at a subsonic cruise with all

external carriage.

Drag Supersonic (clean): Drag from the aircraft at a supersonic cruise with no external carriage.

Drag Supersonic (dirty): Drag from the aircraft at a subsonic cruise with all external carriage.

Thrust: The fixed wing aircraft thrust at sea-level-static.

Fuel Consumption: The fuel consumption at sea-level-static.

Maneuverability: Controllable angle of attack

Observability: The aircraft's ability to not be detected.

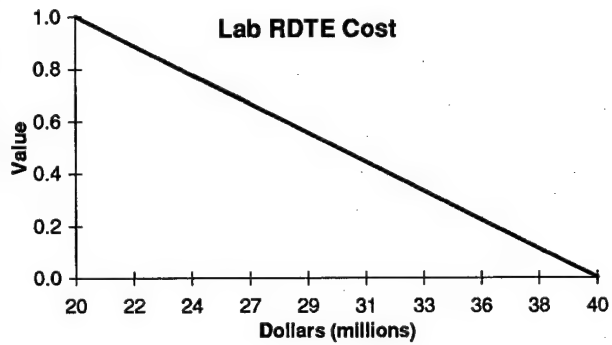
Radar Cross Section: The frontal radar cross section of the fixed wing aircraft.

Infrared Signature: The infrared signature of the fixed wing aircraft.

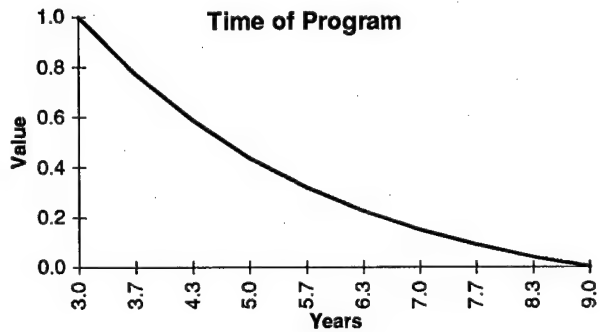
Appendix C

Evaluation Measure Functions

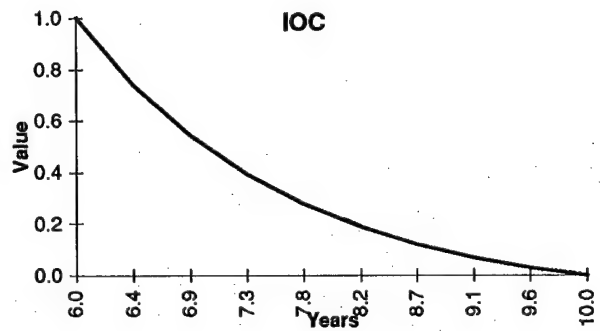
Lab RDTE Cost	
x	Used
Low:	20
High:	40
Mono:	Decreasing
Rho:	Infinity



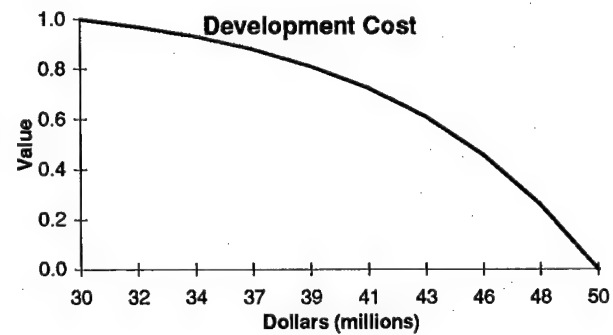
Time of Program	
x	Used
Low:	3
High:	9
Mono:	Decreasing
Rho:	-3



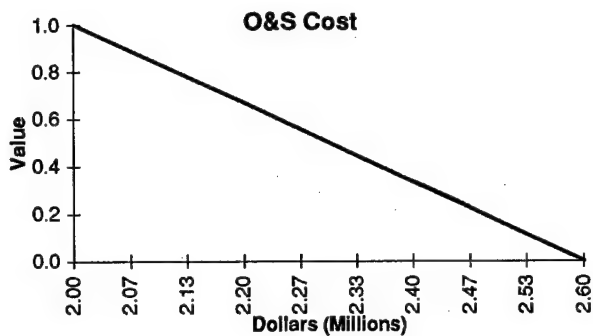
IOC	
x	Used
Low:	6
High:	10
Mono:	Decreasing
Rho:	-1.64



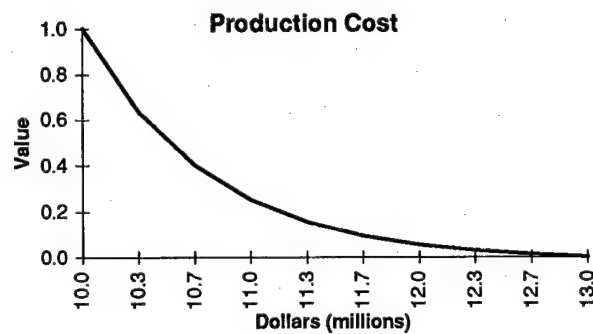
Development Cost	
x	Used
Low:	30
High:	50
Mono:	Decreasing
Rho:	8.2



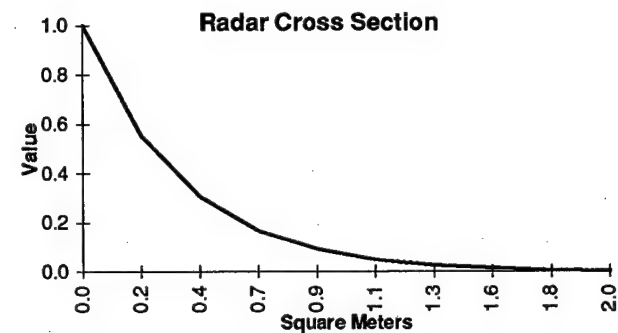
O&S Cost	
x	Used
Low:	2
High:	2.6
Mono:	Decreasing
Rho:	Infinity



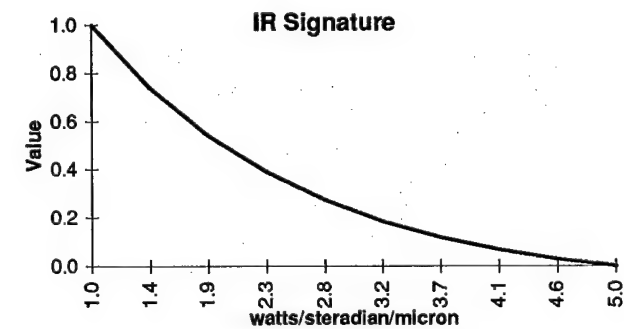
Production Cost	
x	Used
Low:	10
High:	13
Mono:	Decreasing
Rho:	-0.756



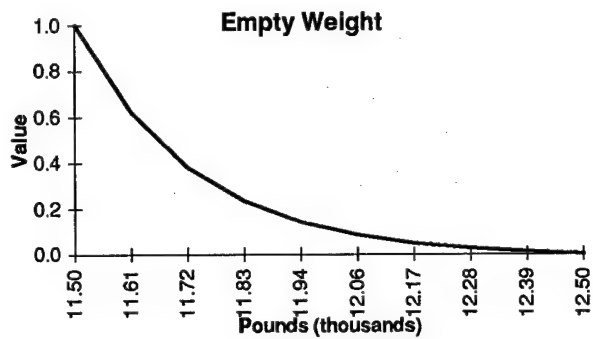
Radar Cross Section	
x	Used
Low:	0
High:	2
Mono:	Decreasing
Rho:	-0.378



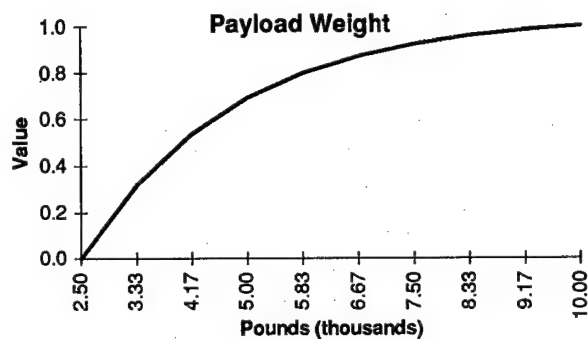
IR Signature	
x	Used
Low:	1
High:	5
Mono:	Decreasing
Rho:	-1.64



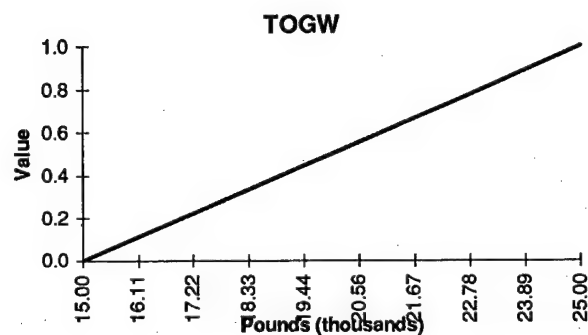
Empty Weight	
x	Used
Low:	11.5
High:	12.5
Mono:	Decreasing
Rho:	-0.236



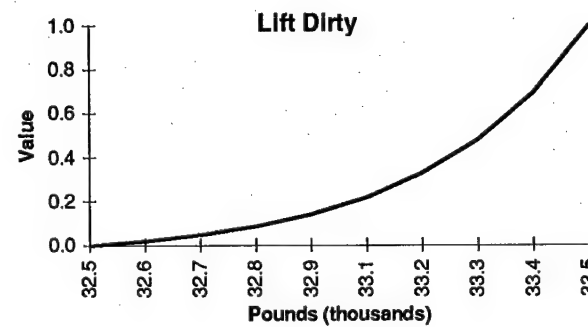
Payload Weight	
x	Used
Low:	2.5
High:	10
Mono:	Increasing
Rho:	2.2875



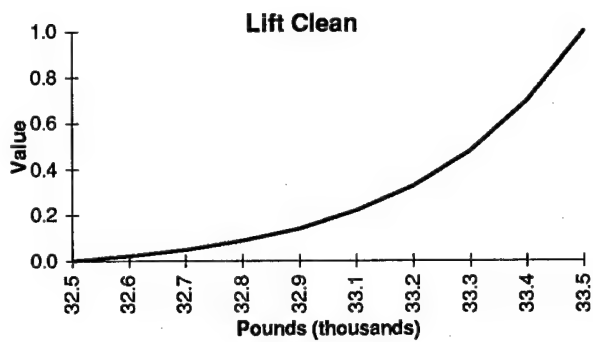
TOGW	
x	Used
Low:	15
High:	25
Mono:	Increasing
Rho:	infinity



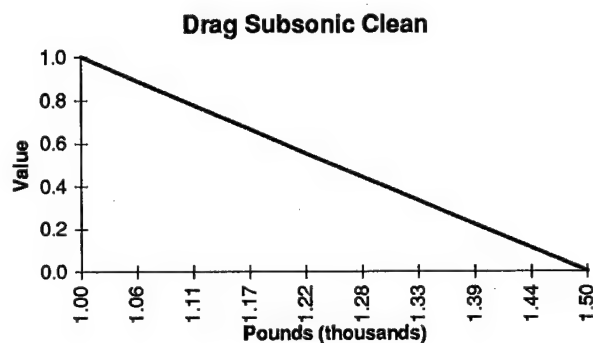
Lift Dirty	
x	Used
Low:	32.5
High:	33.5
Mono:	Increasing
Rho:	-0.324



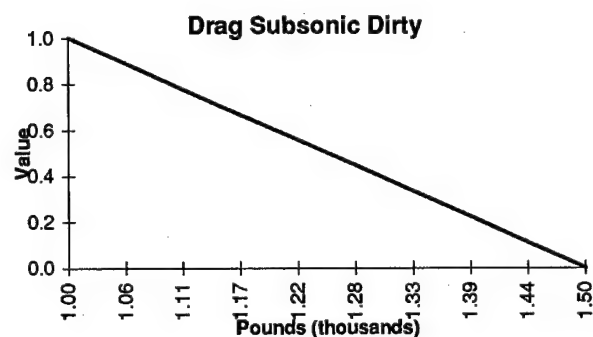
Lift Clean	
x	Used
Low:	32.5
High:	33.5
Mono:	Increasing
Rho:	-0.324



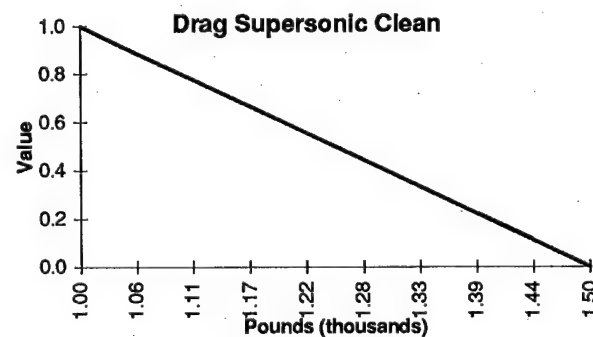
Drag Subsonic Clean	
x	Used
Low:	1
High:	1.5
Mono:	Decreasing
Rho:	Infinity



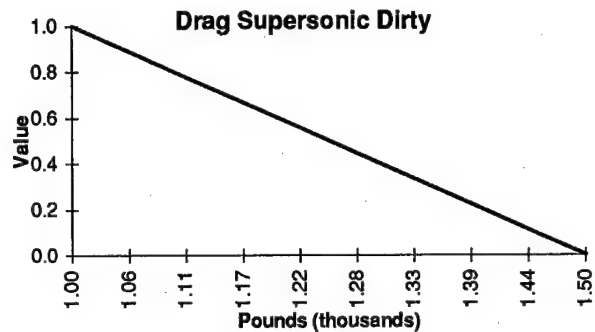
Drag Subsonic Dirty	
x	Used
Low:	1
High:	1.5
Mono:	Decreasing
Rho:	Infinity



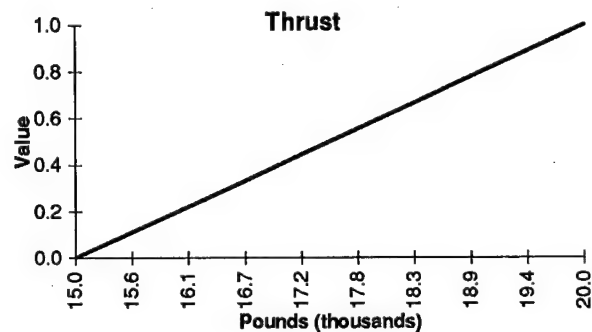
Drag Supersonic Clean	
x	Used
Low:	1
High:	1.5
Mono:	Decreasing
Rho:	Infinity



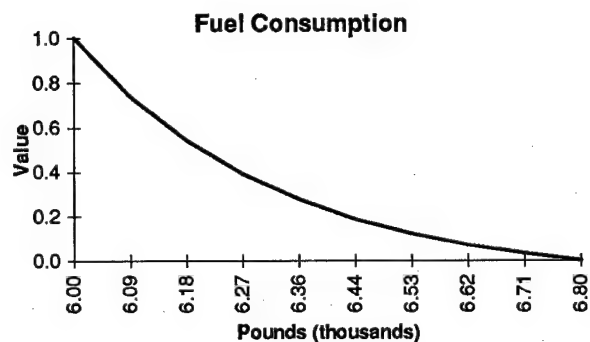
Drag Supersonic Dirty	
x	Used
Low:	1
High:	1.5
Mono:	Decreasing
Rho:	Infinity



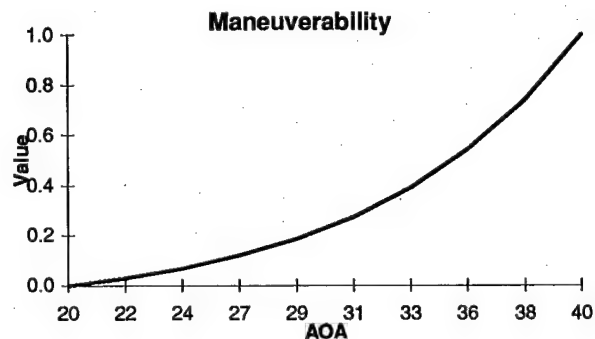
Thrust	
x	Used
Low:	15
High:	20
Mono:	Increasing
Rho:	Infinity



Fuel Consumption	
x	Used
Low:	6
High:	6.8
Mono:	Decreasing
Rho:	-0.328



Maneuverability	
x	Used
Low:	20
High:	40
Mono:	Increasing
Rho:	-8.2



Appendix D

Visual Basic Program for Automated Decision Tool

Program

The following program is the backbone of the automated analysis program that was developed for the AFRL Air Vehicles Integration Division. The code runs as a module in Microsoft Office 95 Excel 7.0. The code documentation explain what each subroutine is doing and also important variables. Visual Basic does not require declaring all variables so only the important ones have been chosen in this program.

```
' These are variables that are used throughout the program
' Index keeps track of the rows when required
Public Index As Integer

' Counter is a standard count for loops
Public Counter As Integer

' Num is used to specify the number of technologies being compared
Public Num As Integer

' This causes the program to automatically execute when the file is opened
' Basically it calls the startup dialog box and then lets the dialog
' box do the work from there.
' When exited the user is told how to restart the program

Sub Auto_Open()
    StartUp
    MsgBox ("To return to the program, go to Tools then StartUp")
End Sub

' This allows the user to call the program after the excel worksheet
' has been activated
Sub StartUp()
    DialogSheets("Startup").Show
End Sub
```

' EvalStart_Click Macro
 ' If the evaluation measure button is selected from the
 ' startup dialog box then the following code is executed.

```
Sub EvalStart_Click()
    EvalMeasures
End Sub
```

' WeightsStart_Click Macro
 ' Similar to the evaluation measures, however this calls
 ' a dialog box to help the user select how
 ' to set the weights

```
Sub WeightsStart_Click()
    DialogSheets("Weightpersonalities").Show
End Sub
```

' this is the data check code.
 ' it merely finds the number of technologies which
 ' will be evaluated and saves the number in a cell.
 ' The program is limited to evaluating 10 technologies.

```
Sub DataEntryStart_Click()
    Num = Application.InputBox _
        ("The number of technologies to be compared.", , "5", Type:=1)
    Do While Num > 10
        Num = Application.InputBox _
            ("The number of technologies must be less than or equal to 10." _
                , , "5", Type:=1)
    Loop
    Range("Model!$A$1").Value = Num
End Sub
```

' DataEvalStart_Click Macro
 ' This calls a dialog box to show the Data evaluation
 ' when the button is selected

```
Sub DataEvalStart_Click()
    DialogSheets("dialogeval").Show
End Sub
```

' SenAnalStart_Click Macro
 ' This pulls up the box to choose the sensitivity
 ' analysis dialog box

```
Sub SenAnalStart_Click()
    DialogSheets("SenAnal").Show
```

End Sub

' UncerStart_Click Macro

' This is the start-up code if the uncertainty analysis button is

' selected

Sub UncerStart_Click()

 DialogSheets("Uncertainty").Show

End Sub

'the execution and ordering for the eval measures code

'each evaluation measure must have it's own dialog box

'also the evaluation measures are equally spaced at 12

'rows a part on the EvaluationMeasures worksheet

Sub EvalMeasures()

 Index = 1

 DialogSheets("LabRDTE").Show

 Index = Index + 12

 DialogSheets("timeofprogram").Show

 Index = Index + 12

 DialogSheets("IOC").Show

 Index = Index + 12

 DialogSheets("Develop").Show

 Index = Index + 12

 DialogSheets("O&S").Show

 Index = Index + 12

 DialogSheets("Product").Show

 Index = Index + 12

 DialogSheets("RCS").Show

 Index = Index + 12

 DialogSheets("IR").Show

 Index = Index + 12

 DialogSheets("EW").Show

 Index = Index + 12

 DialogSheets("Payload").Show

 Index = Index + 12

 DialogSheets("TOGW").Show

 Index = Index + 12

 DialogSheets("Dirty").Show

 Index = Index + 12

 DialogSheets("Clean").Show

 Index = Index + 12

 DialogSheets("Sub").Show

 Index = Index + 12

 DialogSheets("Sub-D").Show

 Index = Index + 12

```

DialogSheets("Super").Show
Index = Index + 12
DialogSheets("Super-D").Show
Index = Index + 12
DialogSheets("Thrust").Show
Index = Index + 12
DialogSheets("Fuel").Show
Index = Index + 12
DialogSheets("Maneuver").Show
Index = Index + 12
End Sub

```

```

' EvalMeas_Show Macro
' The initialization of the evaluation measures information box
' This insures that the correct information is requested and input
' for each evaluation measure. It also puts in the correct default
' values

```

```

Sub EvalMeas_Show()
    Sheets("EvaluationMeasures").Activate
    With ActiveDialog
        .EditBoxes.Text = ""
        .OptionButtons("rhoButton").Value = xlOn
        .EditBoxes("novalue").InputType = xlNumber
        .EditBoxes("allvalue").InputType = xlNumber
    ' since the code function (ValueE) needs the information of
    ' increasing/decreasing this must be used in the code
        If UCase(Cells(Index + 4, 3)) = "INCREASING" Then
            .EditBoxes("novalue").Text = Cells(Index + 2, 4)
            .EditBoxes("allvalue").Text = Cells(Index + 3, 4)
        Else
            .EditBoxes("novalue").Text = Cells(Index + 3, 4)
            .EditBoxes("allvalue").Text = Cells(Index + 2, 4)
        End If
        .EditBoxes("rhovalue").Text = Cells(Index + 5, 4)
    End With
End Sub

```

```

' OKbutton_Click Macro
' once the data is input the information must be stored in a new location
' it is also important to insure the increasing/decreasing is handled
' properly

```

```

Sub OKbutton_Click()
    Sheets("EvaluationMeasures").Activate
    lower = CDBl(DialogSheets("EvalDialog").EditBoxes("novalue").Text)

```

```

higher = CDBl(DialogSheets("EvalDialog").EditBoxes("allvalue").Text)
If DialogSheets("EvalDialog").OptionButtons("rhoButton").Value = xlOn Then
    rhotemp = DialogSheets("EvalDialog").EditBoxes("rhovalue").Text
Else
    R = (lower - DialogSheets("EvalDialog").EditBoxes("midvalue"). _
        Text) / (lower - higher)
    Cells(Index + 6, 3).Select
    ActiveCell.FormulaR1C1 = R
    Worksheets("EvaluationMeasures").Calculate
    Cells(Index + 6, 4).Select
    Rho = ActiveCell.Value
    If Rho = "Infinity" Then
        rhotemp = "Infinity"
    Else
        rhotemp = CDBl(Rho) * Abs(lower - higher)
    End If
End If
If higher < lower Then
    temp = higher
    higher = lower
    lower = temp
    mono = "Decreasing"
Else
    mono = "Increasing"
End If
' this is the actual data input to the worksheet
Cells(Index + 2, 4).Select
ActiveCell.FormulaR1C1 = lower
Cells(Index + 3, 4).Select
ActiveCell.FormulaR1C1 = higher
Cells(Index + 4, 4).Select
ActiveCell.FormulaR1C1 = mono
Cells(Index + 5, 4).Select
ActiveCell.FormulaR1C1 = rhotemp
Worksheets("EvaluationMeasures").Calculate
End Sub

```

' WeightDialog_OKButton_Click Macro
 ' Similar for the evaluation measures, this takes the new data and
 ' stores it on the worksheet. It also checks for mistakes in the input.

```

Sub WeightDialog_OKButton_Click()
    Sheets("Weights").Activate
    temp1 = DialogSheets("WeightDialog").EditBoxes("text1").Text
    Cells(Counter, 2).Select
    If ActiveCell.FormulaR1C1 = "N/A" Then

```

```

    temp1 = "0"
End If
temp2 = DialogSheets("WeightDialog").EditBoxes("text2").Text
Cells(Counter + 1, 2).Select
If ActiveCell.FormulaR1C1 = "N/A" Then
    temp2 = "0"
End If
temp3 = DialogSheets("WeightDialog").EditBoxes("text3").Text
Cells(Counter + 2, 2).Select
If ActiveCell.FormulaR1C1 = "N/A" Then
    temp3 = "0"
End If
temp4 = DialogSheets("WeightDialog").EditBoxes("text4").Text
Cells(Counter + 3, 2).Select
If ActiveCell.FormulaR1C1 = "N/A" Then
    temp4 = "0"
End If
temp5 = DialogSheets("WeightDialog").EditBoxes("text5").Text
Cells(Counter + 4, 2).Select
If ActiveCell.FormulaR1C1 = "N/A" Then
    temp5 = "0"
End If
Cells(Counter, 4).Select
ActiveCell.FormulaR1C1 = temp1
Cells(Counter + 1, 4).Select
ActiveCell.FormulaR1C1 = temp2
Cells(Counter + 2, 4).Select
ActiveCell.FormulaR1C1 = temp3
Cells(Counter + 3, 4).Select
ActiveCell.FormulaR1C1 = temp4
Cells(Counter + 4, 4).Select
ActiveCell.FormulaR1C1 = temp5
Worksheets("Weights").Calculate
End Sub

```

```

' Control the execution of weights assessment
' if own weight adjustment is selected then the weights subroutine
' is called. If the performance based assessment or cost assessments
' are selected then the data from weight-personality is used

```

```

' own_Click Macro
' this allows the individual to select the weights

```

```

Sub own_Click()
    Weights
End Sub

```

```
' current_Click Macro
' This allows the user to see the current settings for each weight.
' This is the cumulative break-down of the weight
```

```
Sub current_Click()
    Calculate
    DialogSheets("weightsetting").Show
End Sub
```

```
' weightsetting_DialogFrame1_Show Macro
' This creates the dialog box that is shown to the user when asked to show
' the current weight settings
```

```
Sub weightsetting_DialogFrame1_Show()
    Sheets("Model").Activate
    With ActiveDialog
        weightvalue = "RDTE = " & Range("B3").Value
        .Labels("RDTE").Caption = weightvalue
        weightvalue = "Time of program = " & Range("C3").Value
        .Labels("time").Caption = weightvalue
        weightvalue = "IOC = " & Range("D3").Value
        .Labels("ioc").Caption = weightvalue
        weightvalue = "Development cost = " & Range("E3").Value
        .Labels("devel").Caption = weightvalue
        weightvalue = "O&S cost = " & Range("F3").Value
        .Labels("os").Caption = weightvalue
        weightvalue = "Production cost = " & Range("G3").Value
        .Labels("product").Caption = weightvalue
        weightvalue = "RCS = " & Range("H3").Value
        .Labels("rcs").Caption = weightvalue
        weightvalue = "IR signature = " & Range("I3").Value
        .Labels("ir").Caption = weightvalue
        weightvalue = "Empty weight = " & Range("J3").Value
        .Labels("ew").Caption = weightvalue
        weightvalue = "Payload weight = " & Range("K3").Value
        .Labels("payload").Caption = weightvalue
        weightvalue = "TOGW = " & Range("L3").Value
        .Labels("togw").Caption = weightvalue
        weightvalue = "Lift-dirty = " & Range("M3").Value
        .Labels("ld").Caption = weightvalue
        weightvalue = "Lift-clean = " & Range("N3").Value
        .Labels("lc").Caption = weightvalue
        weightvalue = "Drag-sub-clean = " & Range("O3").Value
        .Labels("dc").Caption = weightvalue
        weightvalue = "Drag-sub-dirty = " & Range("P3").Value
    End With
End Sub
```

```

.Labels("dd").Caption = weightvalue
weightvalue = "Drag-super-clean = " & Range("Q3").Value
.Labels("dsc").Caption = weightvalue
weightvalue = "Drag-super-dirty = " & Range("R3").Value
.Labels("dsd").Caption = weightvalue
weightvalue = "Thrust = " & Range("S3").Value
.Labels("thrust").Caption = weightvalue
weightvalue = "Fuel consumption = " & Range("T3").Value
.Labels("fuel").Caption = weightvalue
weightvalue = "Maneuverability = " & Range("U3").Value
.Labels("man").Caption = weightvalue
End With
End Sub

' the next three are the preset personality types.
' to change the preset personalities you need to unhide the weightperson
' worksheet and then change the appropriate weight of the sheet.
' Rehide the sheet to clean up the work environment

' perform_Click Macro
Sub perform_Click()
    weightperson (3)
End Sub

' lab_Click Macro
Sub lab_Click()
    weightperson (4)
End Sub

' overall_Click Macro
Sub overall_Click()
    weightperson (5)
End Sub

' this is the subroutine that actually changes the weights for the preset
' personality types.

Sub weightperson(typeperson)
    Sheets("weightperson").Activate
    'impacts
    Range("Weights!$D$5").Value = Cells(4, typeperson)
    'rdte
    Range("Weights!$D$6").Value = Cells(5, typeperson)
    'time of program
    Range("Weights!$D$7").Value = Cells(6, typeperson)
    'cost
    Range("Weights!$D$11").Value = Cells(7, typeperson)

```

'ioc
 Range("Weights!\$D\$12").Value = Cells(8, typeperson)
 'performance
 Range("Weights!\$D\$13").Value = Cells(9, typeperson)
 'develop
 Range("Weights!\$D\$17").Value = Cells(10, typeperson)
 'o&s
 Range("Weights!\$D\$18").Value = Cells(11, typeperson)
 'production
 Range("Weights!\$D\$19").Value = Cells(12, typeperson)
 'mass
 Range("Weights!\$D\$23").Value = Cells(13, typeperson)
 'aero
 Range("Weights!\$D\$24").Value = Cells(14, typeperson)
 'observability
 Range("Weights!\$D\$25").Value = Cells(15, typeperson)
 'ew
 Range("Weights!\$D\$29").Value = Cells(16, typeperson)
 'payload
 Range("Weights!\$D\$30").Value = Cells(17, typeperson)
 'togw
 Range("Weights!\$D\$31").Value = Cells(18, typeperson)
 'lift
 Range("Weights!\$D\$35").Value = Cells(19, typeperson)
 'drag
 Range("Weights!\$D\$36").Value = Cells(20, typeperson)
 'thrust
 Range("Weights!\$D\$37").Value = Cells(21, typeperson)
 'fuel
 Range("Weights!\$D\$38").Value = Cells(22, typeperson)
 'maneuver
 Range("Weights!\$D\$39").Value = Cells(23, typeperson)
 'rcs
 Range("Weights!\$D\$41").Value = Cells(24, typeperson)
 'ir
 Range("Weights!\$D\$42").Value = Cells(25, typeperson)
 'dirty
 Range("Weights!\$D\$47").Value = Cells(26, typeperson)
 'clean
 Range("Weights!\$D\$48").Value = Cells(27, typeperson)
 'subsonic clean
 Range("Weights!\$D\$53").Value = Cells(28, typeperson)
 'subsonic dirty
 Range("Weights!\$D\$54").Value = Cells(29, typeperson)
 'supersonic clean
 Range("Weights!\$D\$55").Value = Cells(30, typeperson)
 'supersonic dirty

```

Range("Weights!$D$56").Value = Cells(31, typeperson)
Worksheets("Weights").Calculate
End Sub

```

' this is the code that changes the weights for the individual that
 ' wants to personally input a new set of weights
 ' All the weight dialogboxes must be called in order to correctly
 ' use the code. The weights are separated by 6 rows.

```

Sub Weights()
    Counter = 5
    DialogSheets("Weights1").Show
    Counter = Counter + 6
    DialogSheets("Weights2").Show
    Counter = 6 + Counter
    DialogSheets("Weights3").Show
    Counter = 6 + Counter
    DialogSheets("Weights4").Show
    Counter = 6 + Counter
    DialogSheets("Weights5").Show
    Counter = 6 + Counter
    DialogSheets("Weights6").Show
    Counter = 6 + Counter
    DialogSheets("Weights7").Show
    Counter = 6 + Counter
    DialogSheets("Weights8").Show
    Counter = 6 + Counter
    DialogSheets("Weights9").Show
End Sub

```

' weight_Show Macro
 ' How to initialize the weights assessment box
 ' This is similar to the evaluation measures initialization

```

Sub weight_Show()
    Sheets("Weights").Activate
    With ActiveDialog
        .EditBoxes.Text = ""
        .EditBoxes("text1").Text = Cells(Counter, 5)
        .EditBoxes("text2").Text = Cells(Counter + 1, 5)
        .EditBoxes("text3").Text = Cells(Counter + 2, 5)
        .EditBoxes("text4").Text = Cells(Counter + 3, 5)
        .EditBoxes("text5").Text = Cells(Counter + 4, 5)
        words = "Weight of " & Cells(Counter, 2)
        .Labels("label1").Caption = words
        words = "Weight of " & Cells(Counter + 1, 2)
        .Labels("label2").Caption = words
    End With
End Sub

```

```

        words = "Weight of " & Cells(Counter + 2, 2)
        .Labels("label3").Caption = words
        words = "Weight of " & Cells(Counter + 3, 2)
        .Labels("label4").Caption = words
        words = "Weight of " & Cells(Counter + 4, 2)
        .Labels("label5").Caption = words
    End With
End Sub

' NoButton_Click Macro
' The noButton execution for the evalmeasures assessments
' This is done for each evaluation measure dialog box.
' It allows the user to see the dialog box to change the evaluation
' measure's value function

Sub NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub

' Risk_NoButton_Click Macro
'

Sub Risk_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub

' IOC_NoButton_Click Macro
'

Sub IOC_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub

' timeofprogram_NoButton_Click Macro
'

Sub timeofprogram_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub

' YesButton_Click Macro
'

Sub YesButton_Click()
End Sub

' Develop_NoButton_Click Macro
'

Sub Develop_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub

```

```

' OS_NoButton_Click Macro
'
Sub OS_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' Product_NoButton_Click Macro
'
Sub Product_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' RCS_NoButton_Click Macro
'
Sub RCS_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' IR_NoButton_Click Macro
'
Sub IR_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' EW_NoButton_Click Macro
'
Sub EW_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' Payload_NoButton_Click Macro
'
Sub Payload_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' TOGW_NoButton_Click Macro
'
Sub TOGW_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' Dirty_NoButton_Click Macro
'
Sub Dirty_NoButton_Click()
    DialogSheets("EvalDialog").Show

```

```

End Sub
'
' Clean_NoButton_Click Macro
'
Sub Clean_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' Sub_NoButton_Click Macro
'
Sub Sub_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' SuD_NoButton_Click Macro
'
Sub SuD_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' Super_NoButton_Click Macro
'
Sub Super_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' SuperD_NoButton_Click Macro
'
Sub SuperD_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' Thrust_NoButton_Click Macro
'
Sub Thrust_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' Fuel_NoButton_Click Macro
'
Sub Fuel_NoButton_Click()
    DialogSheets("EvalDialog").Show
End Sub
'
' Maneuv_Button3_Click Macro
' This is the No Button
'

```

```

Sub Maneuv_Button3_Click()
    DialogSheets("EvalDialog").Show
End Sub

'the nobutton info for the weights assessment
' Button3_Click Macro
'this is for weights1
,

Sub Button3_Click()
    DialogSheets("WeightDialog").Show
End Sub
,

'Weights2_Button3_Click Macro
,

Sub Weights2_Button3_Click()
    DialogSheets("WeightDialog").Show
End Sub
,

'Weights3_NoButton_Click Macro
,

Sub Weights3_NoButton_Click()
    DialogSheets("WeightDialog").Show
End Sub
,

'Weights4_NoButton_Click Macro
,

Sub Weights4_NoButton_Click()
    DialogSheets("WeightDialog").Show
End Sub
,

'Weights5_NoButton_Click Macro
,

Sub Weights5_NoButton_Click()
    DialogSheets("WeightDialog").Show
End Sub
,

'Weights6_NoButton_Click Macro
,

Sub Weights6_NoButton_Click()
    DialogSheets("WeightDialog").Show
End Sub
,

'Weights7_Button3_Click Macro
,

Sub Weights7_Button3_Click()
    DialogSheets("WeightDialog").Show
End Sub

```

' Weights8_Button3_Click Macro

```
Sub Weights8_Button3_Click()  
    DialogSheets("WeightDialog").Show  
End Sub
```

' Dialog27_Button3_Click Macro

' Actually refers to weights9

```
Sub Dialog27_Button3_Click()  
    DialogSheets("WeightDialog").Show  
End Sub
```

' Button2_Click Macro

' This gets the sensitivity analysis working

' There are different versions working to save code space; however,
' the code used for 5 way sensitivity analysis can be used for all
' of the versions, with only the first ones being called for use.

Sub Button2_Click()

```
    Num = Range("Model!$A$1").Value  
    Sheets("Weights").Activate  
    Range(Cells(68, 3), Cells(79, 13)).Select  
    Selection.Copy  
    Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _  
        SkipBlanks:=False, Transpose:=False
```

'3 item sensitivity analysis weights 1

If DialogSheets("SenAnal").OptionButtons("impacts").Value = xlOn Then

```
    Range("F5").Select  
    ActiveCell.FormulaR1C1 = "=RC[-1]"  
    Range("F6").Select  
    ActiveCell.FormulaR1C1 = _  
        "=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[1]C[-1]+R[2]C[-1])"  
    Range("F7").Select  
    ActiveCell.FormulaR1C1 = _  
        "=(1-R[-2]C)*(RC[-1])/(R[-1]C[-1]+RC[-1]+R[1]C[-1])"  
    Range("F8").Select  
    ActiveCell.FormulaR1C1 = _  
        "=(1-R[-3]C)*(RC[-1])/(R[-2]C[-1]+R[-1]C[-1]+RC[-1])"  
    Range(Cells(68, 2), Cells(68 + Num, 13)).Select  
    Selection.Table RowInput:=Range("F5")  
    titlename = "Aircraft Impacts"  
    vertline = "F5"
```

ElseIf DialogSheets("SenAnal").OptionButtons("RDTE").Value = xlOn Then

```

Range("F6").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F5").Select
ActiveCell.FormulaR1C1 = _
    "=(1-R[1]C)*(RC[-1])/(RC[-1]+R[2]C[-1]+R[3]C[-1])"
Range("F7").Select
ActiveCell.FormulaR1C1 = _
    "=(1-R[-1]C)*(RC[-1])/(R[-2]C[-1]+RC[-1]+R[1]C[-1])"
Range("F8").Select
ActiveCell.FormulaR1C1 = _
    "=(1-R[-2]C)*(RC[-1])/(R[-3]C[-1]+R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F6")
titlename = "Lab RDTE Cost"
vertline = "F6"
ElseIf DialogSheets("SenAnal").OptionButtons("program").Value = xlOn Then
Range("F7").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F5").Select
ActiveCell.FormulaR1C1 = _
    "=(1-R[2]C)*(RC[-1])/(RC[-1]+R[1]C[-1]+R[3]C[-1])"
Range("F6").Select
ActiveCell.FormulaR1C1 = _
    "=(1-R[1]C)*(RC[-1])/(R[-1]C[-1]+RC[-1]+R[2]C[-1])"
Range("F8").Select
ActiveCell.FormulaR1C1 = _
    "=(1-R[-1]C)*(RC[-1])/(R[-3]C[-1]+R[-2]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F7")
titlename = "Time of Program"
vertline = "F7"

'3 item sensitivity analysis Weights 2
ElseIf DialogSheets("SenAnal").OptionButtons("cost").Value = xlOn Then
Range("F11").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F12").Select
ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[1]C[-1])"
Range("F13").Select
ActiveCell.FormulaR1C1 = "=(1-R[-2]C)*(RC[-1])/(R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F11")
titlename = "Cost"
vertline = "F11"
ElseIf DialogSheets("SenAnal").OptionButtons("IOC").Value = xlOn Then
Range("F12").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"

```

```

Range("F11").Select
ActiveCell.FormulaR1C1 = "=(1-R[1]C)*(RC[-1])/(R[2]C[-1]+RC[-1])"
Range("F13").Select
ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[-2]C[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F12")
titlename = "IOC"
vertline = "F12"
ElseIf DialogSheets("SenAnal").OptionButtons("perform").Value = xlOn Then
Range("F13").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F11").Select
ActiveCell.FormulaR1C1 = "=(1-R[2]C)*(RC[-1])/(RC[-1]+R[1]C[-1])"
Range("F12").Select
ActiveCell.FormulaR1C1 = "=(1-R[1]C)*(RC[-1])/(R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F13")
titlename = "Performance"
vertline = "F13"

'3 item sensitivity analysis Weights 3
ElseIf DialogSheets("SenAnal").OptionButtons("develop").Value = xlOn Then
Range("F17").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F18").Select
ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[1]C[-1])"
Range("F19").Select
ActiveCell.FormulaR1C1 = "=(1-R[-2]C)*(RC[-1])/(R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F17")
titlename = "Development Cost"
vertline = "F17"
ElseIf DialogSheets("SenAnal").OptionButtons("OS").Value = xlOn Then
Range("F18").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F17").Select
ActiveCell.FormulaR1C1 = "=(1-R[1]C)*(RC[-1])/(R[2]C[-1]+RC[-1])"
Range("F19").Select
ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[-2]C[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F18")
titlename = "O&S Cost"
vertline = "F18"
ElseIf DialogSheets("SenAnal").OptionButtons("product").Value = xlOn Then
Range("F19").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F17").Select

```

```

ActiveCell.FormulaR1C1 = "=(1-R[2]C)*(RC[-1])/(RC[-1]+R[1]C[-1])"
Range("F18").Select
ActiveCell.FormulaR1C1 = "=(1-R[1]C)*(RC[-1])/(R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F19")
titlename = "Production Cost"
vertline = "F19"

```

'3 item sensitivity analysis Weights 4

```

ElseIf DialogSheets("SenAnal").OptionButtons("mass").Value = xlOn Then
Range("F23").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F24").Select
ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[1]C[-1])"
Range("F25").Select
ActiveCell.FormulaR1C1 = "=(1-R[-2]C)*(RC[-1])/(R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F23")
titlename = "Mass"
vertline = "F23"

```

```

ElseIf DialogSheets("SenAnal").OptionButtons("aero").Value = xlOn Then
Range("F24").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F23").Select
ActiveCell.FormulaR1C1 = "=(1-R[1]C)*(RC[-1])/(R[2]C[-1]+RC[-1])"
Range("F25").Select
ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[-2]C[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F24")
titlename = "Aero"
vertline = "F24"

```

```

ElseIf DialogSheets("SenAnal").OptionButtons("observability").Value = xlOn Then
Range("F25").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F23").Select
ActiveCell.FormulaR1C1 = "=(1-R[2]C)*(RC[-1])/(RC[-1]+R[1]C[-1])"
Range("F24").Select
ActiveCell.FormulaR1C1 = "=(1-R[1]C)*(RC[-1])/(R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F25")
titlename = "Observability"
vertline = "F25"

```

'2 item sensitivity analysis weights 5

```

ElseIf DialogSheets("SenAnal").OptionButtons("EW").Value = xlOn Then
Range("F29").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"

```

```

Range("F30").Select
ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[1]C[-1])"
Range("F31").Select
ActiveCell.FormulaR1C1 = "=(1-R[-2]C)*(RC[-1])/(R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F29")
titlename = "Empty Weight"
vertline = "F29"
ElseIf DialogSheets("SenAnal").OptionButtons("payload").Value = xlOn Then
Range("F30").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F29").Select
ActiveCell.FormulaR1C1 = "=(1-R[1]C)*(RC[-1])/(R[2]C[-1]+RC[-1])"
Range("F31").Select
ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[-2]C[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F30")
titlename = "Payload Weight"
vertline = "F30"
ElseIf DialogSheets("SenAnal").OptionButtons("TOGW").Value = xlOn Then
Range("F31").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F29").Select
ActiveCell.FormulaR1C1 = "=(1-R[2]C)*(RC[-1])/(RC[-1]+R[1]C[-1])"
Range("F30").Select
ActiveCell.FormulaR1C1 = "=(1-R[1]C)*(RC[-1])/(R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F31")
titlename = "Observability"
vertline = "F31"

'5 item sensitivity analysis weights 6
ElseIf DialogSheets("SenAnal").OptionButtons("lift").Value = xlOn Then
Range("F35").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F36").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[1]C[-1]+R[2]C[-1]+R[3]C[-1])"
Range("F37").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[-2]C)*(RC[-1])/(R[-1]C[-1]+RC[-1]+R[1]C[-1]+R[2]C[-1])"
Range("F38").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[-3]C)*(RC[-1])/(R[-2]C[-1]+R[-1]C[-1]+RC[-1]+R[1]C[-1])"
Range("F39").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[-4]C)*(RC[-1])/(R[-3]C[-1]+R[-2]C[-1]+R[-1]C[-1]+RC[-1])"

```

```

Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F35")
titlename = "Lift"
vertline = "F35"
ElseIf DialogSheets("SenAnal").OptionButtons("drag").Value = xlOn Then
Range("F36").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F35").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[1]C)*(RC[-1])/(RC[-1]+R[2]C[-1]+R[3]C[-1]+R[4]C[-1])"
Range("F37").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[-1]C)*(RC[-1])/(R[-2]C[-1]+RC[-1]+R[1]C[-1]+R[2]C[-1])"
Range("F38").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[-2]C)*(RC[-1])/(R[-3]C[-1]+R[-1]C[-1]+RC[-1]+R[1]C[-1])"
Range("F39").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[-3]C)*(RC[-1])/(R[-4]C[-1]+R[-2]C[-1]+R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F36")
titlename = "Drag"
vertline = "F36"
ElseIf DialogSheets("SenAnal").OptionButtons("thrust").Value = xlOn Then
Range("F37").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F35").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[2]C)*(RC[-1])/(RC[-1]+R[1]C[-1]+R[3]C[-1]+R[4]C[-1])"
Range("F36").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[1]C)*(RC[-1])/(R[-1]C[-1]+RC[-1]+R[2]C[-1]+R[3]C[-1])"
Range("F38").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[-1]C)*(RC[-1])/(R[-3]C[-1]+R[-2]C[-1]+RC[-1]+R[1]C[-1])"
Range("F39").Select
ActiveCell.FormulaR1C1 = _
"=(1-R[-2]C)*(RC[-1])/(R[-4]C[-1]+R[-3]C[-1]+R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F37")
titlename = "Thrust"
vertline = "F37"
ElseIf DialogSheets("SenAnal").OptionButtons("fuel").Value = xlOn Then
Range("F38").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F35").Select
ActiveCell.FormulaR1C1 = _

```

```

    "= (1-R[3]C)*(RC[-1])/(RC[-1]+R[1]C[-1]+R[2]C[-1]+R[4]C[-1])"
Range("F36").Select
ActiveCell.FormulaR1C1 = _
    "= (1-R[2]C)*(RC[-1])/(R[-1]C[-1]+RC[-1]+R[1]C[-1]+R[3]C[-1])"
Range("F37").Select
ActiveCell.FormulaR1C1 = _
    "= (1-R[1]C)*(RC[-1])/(R[-2]C[-1]+R[-1]C[-1]+RC[-1]+R[2]C[-1])"
Range("F39").Select
ActiveCell.FormulaR1C1 = _
    "= (1-R[-1]C)*(RC[-1])/(R[-4]C[-1]+R[-3]C[-1]+R[-2]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F38")
titlename = "Fuel"
vertline = "F38"
ElseIf DialogSheets("SenAnal").OptionButtons("maneuver").Value = xlOn Then
Range("F39").Select
ActiveCell.FormulaR1C1 = "=RC[-1]"
Range("F35").Select
ActiveCell.FormulaR1C1 = _
    "= (1-R[4]C)*(RC[-1])/(RC[-1]+R[1]C[-1]+R[2]C[-1]+R[3]C[-1])"
Range("F36").Select
ActiveCell.FormulaR1C1 = _
    "= (1-R[3]C)*(RC[-1])/(R[-1]C[-1]+RC[-1]+R[1]C[-1]+R[2]C[-1])"
Range("F37").Select
ActiveCell.FormulaR1C1 = _
    "= (1-R[2]C)*(RC[-1])/(R[-2]C[-1]+R[-1]C[-1]+RC[-1]+R[1]C[-1])"
Range("F38").Select
ActiveCell.FormulaR1C1 = _
    "= (1-R[1]C)*(RC[-1])/(R[-3]C[-1]+R[-2]C[-1]+R[-1]C[-1]+RC[-1])"
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F38")
titlename = "Maneuverability"
vertline = "F39"

'2 item sensitivity analysis weights 7
ElseIf DialogSheets("SenAnal").OptionButtons("RCS").Value = xlOn Then
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F41")
titlename = "RCS (IR signature is the complement)"
vertline = "F41"

'2 item sensitivity analysis weights_8
ElseIf DialogSheets("SenAnal").OptionButtons("dirty").Value = xlOn Then
Range(Cells(68, 2), Cells(68 + Num, 13)).Select
Selection.Table RowInput:=Range("F47")
titlename = "Lift dirty (Lift clean is the complement)"
vertline = "F47"

```

```

'4 item sensitivity analysis weights 9
ElseIf DialogSheets("SenAnal").OptionButtons("sub").Value = xlOn Then
    Range("F53").Select
    ActiveCell.FormulaR1C1 = "=RC[-1]"
    Range("F54").Select
    ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(RC[-1]+R[1]C[-1]+R[2]C[-1])"
    Range("F55").Select
    ActiveCell.FormulaR1C1 = "=(1-R[-2]C)*(RC[-1])/(R[-1]C[-1]+RC[-1]+R[1]C[-1])"
    Range("F56").Select
    ActiveCell.FormulaR1C1 = "=(1-R[-3]C)*(RC[-1])/(R[-2]C[-1]+R[-1]C[-1]+RC[-1])"
    Range(Cells(68, 2), Cells(68 + Num, 13)).Select
    Selection.Table RowInput:=Range("F53")
    titlename = "Subsonic Drag Clean"
    vertline = "F53"
ElseIf DialogSheets("SenAnal").OptionButtons("subd").Value = xlOn Then
    Range("F54").Select
    ActiveCell.FormulaR1C1 = "=RC[-1]"
    Range("F53").Select
    ActiveCell.FormulaR1C1 = "=(1-R[1]C)*(RC[-1])/(RC[-1]+R[2]C[-1]+R[3]C[-1])"
    Range("F55").Select
    ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(R[-2]C[-1]+RC[-1]+R[1]C[-1])"
    Range("F56").Select
    ActiveCell.FormulaR1C1 = "=(1-R[-2]C)*(RC[-1])/(R[-3]C[-1]+R[-1]C[-1]+RC[-1])"
    Range(Cells(68, 2), Cells(68 + Num, 13)).Select
    Selection.Table RowInput:=Range("F54")
    titlename = "Subsonic Drag Dirty"
    vertline = "F54"
ElseIf DialogSheets("SenAnal").OptionButtons("super").Value = xlOn Then
    Range("F55").Select
    ActiveCell.FormulaR1C1 = "=RC[-1]"
    Range("F53").Select
    ActiveCell.FormulaR1C1 = "=(1-R[2]C)*(RC[-1])/(RC[-1]+R[1]C[-1]+R[3]C[-1])"
    Range("F54").Select
    ActiveCell.FormulaR1C1 = "=(1-R[1]C)*(RC[-1])/(R[-1]C[-1]+RC[-1]+R[2]C[-1])"
    Range("F56").Select
    ActiveCell.FormulaR1C1 = "=(1-R[-1]C)*(RC[-1])/(R[-3]C[-1]+R[-2]C[-1]+RC[-1])"
    Range(Cells(68, 2), Cells(68 + Num, 13)).Select
    Selection.Table RowInput:=Range("F55")
    titlename = "Supersonic Drag Clean"
    vertline = "F55"
ElseIf DialogSheets("SenAnal").OptionButtons("superd"). _
    Value = xlOn Then
    Range("F56").Select
    ActiveCell.FormulaR1C1 = "=RC[-1]"
    Range("F53").Select
    ActiveCell.FormulaR1C1 = _

```

```

    "= (1-R[3]C)*(RC[-1])/(RC[-1]+R[1]C[-1]+R[2]C[-1])"
    Range("F54").Select
    ActiveCell.FormulaR1C1 = _
    "= (1-R[2]C)*(RC[-1])/(R[-1]C[-1]+RC[-1]+R[1]C[-1])"
    Range("F55").Select
    ActiveCell.FormulaR1C1 = _
    "= (1-R[1]C)*(RC[-1])/(R[-2]C[-1]+R[-1]C[-1]+RC[-1])"
    Range(Cells(68, 2), Cells(68 + Num, 13)).Select
    Selection.Table RowInput:=Range("F56")
    titlename = "Supersonic Drag Dirty"
    vertline = "F56"
End If
' now the sensitivity functions have been updated the old chart must be
' deleted then a new chart created with the proper title
' Then the chart must be copied to the dialog box that is shown
' to the user. This cut and paste properties are different
' in office 97. Then the dialog box is shown.
ActiveSheet.ChartObjects("sensit").Delete
current = Range(vertline).Value
titletext = "Weight of " & titlename & " currently " & current
ActiveSheet.ChartObjects.Add(45, 897, 346.5, 194.25).Select
Calculate
ActiveChart.ChartWizard Source:=Range(Cells(80, 2), _
Cells(80 + Num, 13)), Gallery:= _
xlLine, Format:=2, PlotBy:=xlRows, CategoryLabels:=1, _
SeriesLabels:=1, HasLegend:=1, Title:="", CategoryTitle:= _
titletext, ValueTitle:="Value", ExtraTitle:=""
Selection.Name = "sensit"
Sheets("sendialog").Select
ActiveSheet.DrawingObjects("sensit").Select
Selection.Delete
Sheets("Weights").Select
ActiveSheet.DrawingObjects("sensit").Select
Selection.Copy
Sheets("sendialog").Select
ActiveSheet.Paste
Selection.Left = 73.5
Selection.Top = 36.75
Sheets("Weights").Select
DialogSheets("sendialog").Show
End Sub

' DataEntryStart_Click Macro
' show_Click Macro
' This does the same type of thing as the previous code however it waits
' to find out the type of evaluation the user wants then creates the

```

' chart as requested.

Sub show_Click()

Num = Range("Model!\$A\$1").Value

Sheets("Model").Activate

ActiveSheet.ChartObjects("dataeval").Delete

If DialogSheets("dialogeval").OptionButtons("bar")._

Value = xlOn Then

ActiveSheet.ChartObjects.Add(45, 667, 346.5, 194.25).Select

Calculate

ActiveChart.ChartWizard _

Source:=Sheets("Model").Range(Cells(60, 1), _

Cells(60 + Num, 2)), Gallery:=xlColumn, _

Format:=3, PlotBy:=xlColumns, CategoryLabels:=1, _

SeriesLabels:=1, HasLegend:=1, Title:="", _

CategoryTitle:="Technology", ValueTitle:="Value", _

ExtraTitle:=""

ElseIf DialogSheets("dialogeval").OptionButtons("main")._

Value = xlOn Then

ActiveSheet.ChartObjects.Add(45, 667, 346.5, 194.25).Select

Calculate

ActiveChart.ChartWizard _

Source:=Sheets("Model").Range(Cells(48, 1), _

Cells(48 + Num, 8)), Gallery:=xlColumn, _

Format:=3, PlotBy:=xlColumns, CategoryLabels:=1, _

SeriesLabels:=1, HasLegend:=1, Title:="", _

CategoryTitle:="Technology", _

ValueTitle:="Value", ExtraTitle:=""

Else

ActiveSheet.ChartObjects.Add(45, 667, 346.5, 194.25).Select

Calculate

ActiveChart.ChartWizard _

Source:=Sheets("Model").Range(Cells(36, 1), _

Cells(36 + Num, 21)), Gallery:=xlColumn, _

Format:=3, PlotBy:=xlColumns, CategoryLabels:=1, _

SeriesLabels:=1, HasLegend:=1, Title:="", _

CategoryTitle:="Technology", _

ValueTitle:="Value", ExtraTitle:=""

End If

Selection.Name = "dataeval"

Sheets("datachart").Select

ActiveSheet.DrawingObjects("dataeval").Select

Selection.Delete

Sheets("Model").Select

ActiveSheet.DrawingObjects("dataeval").Select

Selection.Copy

Sheets("datachart").Select

```

ActiveSheet.Paste
Selection.Left = 73.5
Selection.Top = 36.75
Sheets("Model").Select
DialogSheets("datachart").Show
End Sub

```

```

' DialogFrame1_Show Macro
' for uncertainty dialog sheet
' This causes the uncertainty analysis dialog box be empty
' when the user calls it up.

```

```

Sub DialogFrame1_Show()
    With ActiveDialog
        .CheckBoxes.Value = False
    End With
End Sub

```

```

' Uncertainty_okbutton_Click Macro
' This counts the number of uncertain technologies then calls
' different type of analysis procedure to be called for the number
' of uncertain variables. Then it calls the procedure to create the
' CDF for the data.
' The variable "place" shifts the recorded location for each new
' uncertain evaluation measure. :Number: is the count for the number
' of uncertain variables. Only the first five uncertain variables
' will be used

```

```

Sub Uncertainty_okbutton_Click()
    Num = Range("Model!$A$1").Value
    Sheets("data").Activate
    number = 0
    place = 2
    rownum = 102
    If DialogSheets("Uncertainty").CheckBoxes("box1").Value = _
        xlOn Then
        number = number + 1
        Cells(rownum, place) = 1
        place = place + 1
    End If
    If DialogSheets("Uncertainty").CheckBoxes("box2").Value = _
        xlOn Then
        number = number + 1
        Cells(rownum, place) = 2
        place = place + 1
    End If

```

```

End If
If DialogSheets("Uncertainty").CheckBoxes("box3").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 3
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box4").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 4
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box5").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 5
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box6").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 6
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box7").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 7
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box8").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 8
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box9").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 9
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box10").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 10

```

```

    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box11").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 11
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box12").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 12
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box13").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 13
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box14").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 14
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box15").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 15
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box16").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 16
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box17").Value = _
    xlOn Then
    number = number + 1
    Cells(rownum, place) = 17
    place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box18").Value = _
    xlOn Then
    number = number + 1

```

```

Cells(rownum, place) = 18
place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box19").Value = _
xlOn Then
number = number + 1
Cells(rownum, place) = 19
place = place + 1
End If
If DialogSheets("Uncertainty").CheckBoxes("box20").Value = _
xlOn Then
number = number + 1
Cells(rownum, place) = 20
place = place + 1
End If
If number > 5 Then
MsgBox ("Only the first 5 uncertain events will be used")
Uncertainty_Anal5
End If
If number = 1 Then
Uncertainty_Anal1
End If
If number = 2 Then
MsgBox ("Please allow the computer a few minutes.")
Uncertainty_Anal2
End If
If number = 3 Then
MsgBox ("Please allow the computer a few minutes.")
Uncertainty_Anal3
End If
If number = 4 Then
MsgBox ("Please allow the computer up to 5 minutes.")
Uncertainty_Anal4
End If
If number = 5 Then
MsgBox ("Please allow the computer up to 20 minutes.")
Uncertainty_Anal5
End If
cdf
End Sub

```

' This is the uncertainty analysis for only one uncertain variable
' The worksheet is calculated 3 times

```

Sub Uncertainty_Anal1()
Num = Range("Model!$A$1").Value

```

```

Sheets("data").Activate
rowindex = 105
For account = 1 To 3
    per = 1
    per = percentage(account, per)
    eval1 = Cells(102, 2)
    For techn = 1 To Num
        Cells(4 + eval1, techn + 1) = _
            Cells(4 + eval1 + account * 25, techn + 1)
    Next techn
    Calculate
    Cells(rowindex, 1) = per
    For techn = 1 To Num
        Cells(rowindex, techn + 1) = _
            Cells(104, techn + 1)
    Next techn
    rowindex = rowindex + 1
Next account
Cells(103, 2) = rowindex - 105
End Sub

```

' This is the uncertainty analysis for two uncertain variables
 ' The worksheet is calculated 9 times

```

Sub Uncertainty_Anal2()
    Num = Range("Model!$A$1").Value
    Sheets("data").Activate
    rowindex = 105
    For account = 1 To 3
        eval1 = Cells(102, 2)
        For techn = 1 To Num
            Cells(4 + eval1, techn + 1) = _
                Cells(4 + eval1 + account * 25, techn + 1)
        Next techn
        For bcount = 1 To 3
            per = 1
            per = percentage(account, per)
            per = percentage(bcount, per)
            eval2 = Cells(102, 3)
            For techn = 1 To Num
                Cells(4 + eval2, techn + 1) = _
                    Cells(4 + eval2 + bcount * 25, techn + 1)
            Next techn
            Calculate
            Cells(rowindex, 1) = per
            For techn = 1 To Num

```

```

        Cells(rowindex, techn + 1) = _
            Cells(104, techn + 1)
    Next techn
    rowindex = rowindex + 1
Next bcount
Next account
Cells(103, 2) = rowindex - 105
End Sub

```

' This is the uncertainty analysis for three uncertain variables
 ' The worksheet is calculated 27 times

```

Sub Uncertainty_Anal3()
    Num = Range("Model!$A$1").Value
    Sheets("data").Activate
    rowindex = 105
    For account = 1 To 3
        eval1 = Cells(102, 2)
        For techn = 1 To Num
            Cells(4 + eval1, techn + 1) = _
                Cells(4 + eval1 + account * 25, techn + 1)
        Next techn
        For bcount = 1 To 3
            eval2 = Cells(102, 3)
            For techn = 1 To Num
                Cells(4 + eval2, techn + 1) = _
                    Cells(4 + eval2 + bcount * 25, techn + 1)
            Next techn
            For ccount = 1 To 3
                eval3 = Cells(102, 4)
                For techn = 1 To Num
                    Cells(4 + eval3, techn + 1) = _
                        Cells(4 + eval3 + ccount * 25, techn + 1)
                Next techn
                per = 1
                per = percentage(account, per)
                per = percentage(bcount, per)
                per = percentage(ccount, per)
                Calculate
                Cells(rowindex, 1) = per
                For techn = 1 To Num
                    Cells(rowindex, techn + 1) = _
                        Cells(104, techn + 1)
                Next techn
                rowindex = rowindex + 1
            Next ccount
        Next account
    Next account
End Sub

```

```

    Next bcount
  Next account
  Cells(103, 2) = rowindex - 105
End Sub

```

```

' This is the uncertainty analysis for four uncertain variables
' The worksheet is calculated 81 times

```

```

Sub Uncertainty_Anal4()
  Num = Range("Model!$A$1").Value
  Sheets("data").Activate
  rowindex = 105
  For account = 1 To 3
    eval1 = Cells(102, 2)
    For techn = 1 To Num
      Cells(4 + eval1, techn + 1) = _
        Cells(4 + eval1 + account * 25, techn + 1)
    Next techn
    For bcount = 1 To 3
      eval2 = Cells(102, 3)
      For techn = 1 To Num
        Cells(4 + eval2, techn + 1) = _
          Cells(4 + eval2 + bcount * 25, techn + 1)
      Next techn
      For ccount = 1 To 3
        eval3 = Cells(102, 4)
        For techn = 1 To Num
          Cells(4 + eval3, techn + 1) = _
            Cells(4 + eval3 + ccount * 25, techn + 1)
        Next techn
        For ecount = 1 To 3
          eval4 = Cells(102, 5)
          For techn = 1 To Num
            Cells(4 + eval4, techn + 1) = _
              Cells(4 + eval4 + ecount * 25, techn + 1)
          Next techn
          per = 1
          per = percentage(account, per)
          per = percentage(bcount, per)
          per = percentage(ccount, per)
          per = percentage(ecount, per)
          Calculate
          Cells(rowindex, 1) = per
          For techn = 1 To Num
            Cells(rowindex, techn + 1) = _
              Cells(104, techn + 1)
          Next techn
        Next ecount
      Next ccount
    Next bcount
  Next account
End Sub

```

```

        Next techn
        rowindex = rowindex + 1
    Next ecount
Next ccount
Next bcount
Next account
Cells(103, 2) = rowindex - 105
End Sub

```

' This is the uncertainty analysis for five or more
' uncertain variables. The worksheet is calculated 243 times

```

Sub Uncertainty_Anal5()
    Num = Range("Model!$A$1").Value
    Sheets("data").Activate
    rowindex = 105
    For account = 1 To 3
        eval1 = Cells(102, 2)
        For techn = 1 To Num
            Cells(4 + eval1, techn + 1) = _
                Cells(4 + eval1 + account * 25, techn + 1)
        Next techn
        For bcount = 1 To 3
            eval2 = Cells(102, 3)
            For techn = 1 To Num
                Cells(4 + eval2, techn + 1) = _
                    Cells(4 + eval2 + bcount * 25, techn + 1)
            Next techn
            For ccount = 1 To 3
                eval3 = Cells(102, 4)
                For techn = 1 To Num
                    Cells(4 + eval3, techn + 1) = _
                        Cells(4 + eval3 + ccount * 25, techn + 1)
                Next techn
                For ecount = 1 To 3
                    eval4 = Cells(102, 5)
                    For techn = 1 To Num
                        Cells(4 + eval4, techn + 1) = _
                            Cells(4 + eval4 + ecount * 25, techn + 1)
                    Next techn
                    For fcount = 1 To 3
                        eval5 = Cells(102, 6)
                        For techn = 1 To Num
                            Cells(4 + eval5, techn + 1) = _
                                Cells(4 + eval5 + fcount * _
                                    25, techn + 1)
                        Next techn
                    Next fcount
                Next ecount
            Next ccount
        Next bcount
    Next account
End Sub

```

```

        Next techn
        per = 1
        per = percentage(acount, per)
        per = percentage(bcount, per)
        per = percentage(ccount, per)
        per = percentage(ecount, per)
        per = percentage(fcount, per)
        Calculate
        Cells(rowindex, 1) = per
        For techn = 1 To Num
            Cells(rowindex, techn + 1) = _
                Cells(104, techn + 1)
        Next techn
        rowindex = rowindex + 1
    Next fcount
Next ecount
Next ccount
Next bcount
Next account
Cells(103, 2) = rowindex - 105
End Sub

```

' This compiles the data from the uncertain points and then
 ' combines the valued that are within .01 of each other and
 ' adds then probability. Then the cumulative density function
 ' prepared. Finally the data is put on a chart and displayed to the
 ' user. MinBest and Maxbest are used to scale the graph to a viewable
 ' chart size.

```

Sub cdf()
    Num = Range("Model!$A$1").Value
    datapoints = Range("Data!$B$103").Value
    Sheets("data").Activate
    Range("N100:W199").Delete
    For techn = 1 To Num
        rowindex = 105
        Range(Cells(105, 1), Cells(104 + datapoints, 1 + techn)).Select
        If techn = 1 Then
            Selection.Sort Key1:=Range("B105"), Order1:= _
                xlAscending, Header:=xlGuess, OrderCustom:=1, _
                MatchCase:=False, Orientation:=xlTopToBottom
        ElseIf techn = 2 Then
            Selection.Sort Key1:=Range("C105"), Order1:= _
                xlAscending, Header:=xlGuess, OrderCustom:=1, _
                MatchCase:=False, Orientation:=xlTopToBottom
        ElseIf techn = 3 Then

```

```

Selection.Sort Key1:=Range("D105"), Order1:= _
    xlAscending, Header:=xlGuess, OrderCustom:=1, _
    MatchCase:=False, Orientation:=xlTopToBottom
ElseIf techn = 4 Then
Selection.Sort Key1:=Range("E105"), Order1:= _
    xlAscending, Header:=xlGuess, OrderCustom:=1, _
    MatchCase:=False, Orientation:=xlTopToBottom
Else
Selection.Sort Key1:=Range("F105"), Order1:= _
    xlAscending, Header:=xlGuess, OrderCustom:=1, _
    MatchCase:=False, Orientation:=xlTopToBottom
End If
For histindex = 100 To 199
    If Cells(histindex, 13) < Cells(rowindex, 1 + techn) Then
        Cells(histindex, 13 + techn) = 0
    Else
        While Cells(histindex, 13) > Cells(rowindex, _
            1 + techn) And rowindex < 105 + datapoints
            Cells(histindex, 13 + techn) = _
                Cells(histindex, 13 + techn) _
                + Cells(rowindex, 1)
            rowindex = rowindex + 1
        Wend
    End If
    If histindex > 100 Then
        Cells(histindex, 13 + techn) = _
            Cells(histindex - 1, 13 + techn) + _
            Cells(histindex, 13 + techn)
    End If
    Next histindex
Next techn
ActiveSheet.ChartObjects("unsit").Delete
minbest = 199
For techn = 1 To Num
    rowindex = 100
    While Cells(rowindex, 13 + techn) = 0
        techmin = rowindex
        rowindex = rowindex + 1
    Wend
    If techmin < minbest Then
        minbest = techmin
    End If
Next techn
minbest = minbest - 4
If minbest < 100 Then
    minbest = 99
End If

```

```

maxbest = 100
For techn = 1 To Num
    rowindex = 199
    While Cells(rowindex, 13 + techn) = 1
        techmax = rowindex
        rowindex = rowindex - 1
    Wend
    If techmax > maxbest Then
        maxbest = techmax
    End If
    Cells(minbest, 13 + techn) = Cells(99, 13 + techn)
Next techn
maxbest = maxbest + 5
If maxbest > 199 Then
    maxbest = 199
End If
ActiveSheet.ChartObjects.Add(587, 1281, 375, 224).Select
ActiveChart.ChartWizard _
    Source:=Range(Cells(minbest, 13), Cells(maxbest, _
    13 + Num)), Gallery:=xlLine, Format:=2, PlotBy:= _
    xlColumns, CategoryLabels:=1, SeriesLabels _
    :=1, HasLegend:=1, Title:="CDF", CategoryTitle:= _
    "Value", ValueTitle:="Probability", ExtraTitle:=""
Selection.Name = "unsit"
Sheets("uncerdialog").Select
ActiveSheet.ChartObjects("unsit").Delete
Sheets("data").Select
ActiveSheet.ChartObjects("unsit").Select
Selection.Copy
Sheets("uncerdialog").Select
ActiveSheet.Paste
Selection.Left = 73.5
Selection.Top = 36.75
Sheets("data").Select
DialogSheets("uncerdialog").Show
End Sub

```

Functions

The following functions are called by the program and also by the various worksheets. The ValueE function, was created by Kirkwood and is found in Strategic Decision Making page 81.

' This formula takes the five important characteristics
 ' for an exponential value function and returns the value
 ' This is for use with a monatomic function only (i.e. constantly
 ' increasing or constantly decreasing). This is used on the worksheet
 ' "Model"

```
Function ValueE(x, Low, High, Monotonicity, Rho)
  Select Case UCase(Monotonicity)
    Case "INCREASING"
      Difference = x - Low
    Case "DECREASING"
      Difference = High - x
  End Select
  If UCase(Rho) = "INFINITY" Then
    ValueE = Difference / (High - Low)
  Else
    ValueE = (1 - Exp(-Difference / Rho)) / (1 - Exp(-(High - Low) / Rho))
  End If
End Function
```

' This checks to see if the data is beyond the bounds for the value
 ' of the exponential value function. If the data is out of the bounds,
 ' the upper/ lower bound is used instead. This is also used on the
 ' worksheet "Model"

```
Function Check(data, min, max)
  If min > max Then
    temp = min
    min = max
    max = temp
  End If
  If data < min Then
    Check = min
  ElseIf data > max Then
    Check = max
  Else
    Check = data
  End If
End Function
```

' This function carries a constant multiplication depending on the
 ' type of uncertainty associated with the point.
 ' This is used in the subroutine cdf

```
Function percentage(factor, percent)
  If factor = 3 Then
    percentage = percent * 0.63
  Else
    percentage = percent * 0.185
  End If
End Function
```

Bibliography

- Air Force Research Laboratory. WWWeb, <http://www.afrl.af.mil/misvis.html>. 15 February 1998.
- Air Force Research Laboratory. WWWeb, <http://www.afrl.af.mil/av.html>. 15 February 1998.
- Barrager, Stephen and Oliver Gildersleeve. "A Methodology to Incorporate Uncertainty Into R&D Cost and Performance Data," Resources and Energy 11: 177-193 (1989).
- Belton, Valerie. "A comparison of the analytic hierarchy process and a simple multi-attribute value function," European Journal of Operations: Vol.7, No. 21, 7-21 (1986).
- Brown, Squire. Aeronautical Engineer, Engineering Directorate, Aeronautical Systems Center, Wright-Patterson AFB OH. Personal Interview. 18 November 1997.
- Carter, Dennis L. Senior Aerospace Engineer, Air Vehicles Integration Division Advanced Concepts Branch, AFRL, Wright-Patterson AFB OH. Personal Interview. 11-12 December 1997.
- Clemen, Robert T. Making Hard Decisions. (Second Edition) Belmont: Duxbury Press, 1996.
- Jackson, Jack A. Jr., Brian L. Jones, and Lee J. Lehmuhl. An Operational Analysis for 2025. Maxwell Air Force Base, Alabama, Air University Press, 1996.
- Keeney, Ralph L. "Creativity in Decision Making with Value-Focused Thinking," Sloan Management Review: 33-41 (Summer 1994).
- Kirkwood, Craig W. Strategic Decision Making. Belmont: Duxbury Press, 1997.
- Rouse, Willaim B., Kenneth R. Both, and Beverly G. Sutley Thomas. "Assessing Cost/Benefits of Research and Development Investments," IEEE, Transactions on Systems, Man and Cybernetics- Part A: Systems and Humans: Vol. 27, No. 4, 389-401 (July 1997).

Vita

Second Lieutenant Michael J. Artelli was born in Daytona Beach Florida on March 7th 1974. He received a Bachelor of Science Degree in Mathematical Sciences from the United States Air Force Academy on May 29th 1996. He entered into the School of Engineering, Air Force Institute of Technology in August 1996.

Permanent address: 2940 Cove Crossing Drive
Lawrenceville, Georgia 30245

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE Mar 98		3. REPORT TYPE AND DATES COVERED Master's Thesis
4. TITLE AND SUBTITLE APPLICATION OF DECISION ANALYSIS TO EVALUATE ALTERNATIVE RESEARCH AND DEVELOPMENT INVESTMENTS			5. FUNDING NUMBERS	
6. AUTHOR(S) Michael J. Artelli, 2Lt, USAF				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Institute of Technology 2750 P. Street WPAFB, OH 45433-7765			8. PERFORMING ORGANIZATION REPORT NUMBER AFIT/GOR/ENY/98M-01	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Dennis Carter AFRL/VAOI Bldg 45 2130 Eight Street Ste. 1 WPAFB OH, 45433-7542			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES Advisor: Lt Col Stuart Kramer Phone: 937-255-3636 X4578 e-mail: skramer@afit.af.mil				
12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This thesis is an application of decision analysis techniques to the problem of evaluating competing research and development investments and selecting the best portfolio from among the alternatives. In contrast to the current ad hoc approach, decision analysis provides an explicit and easily explained rationale for investment choices, complete and consistent incorporation of multiple objectives, and direct insight into the effects of uncertain investment returns. A hierarchical objective decomposition was used to capture the user's preference structure. The hierarchy was then used to develop a computer-based decision aid to allow the users to quickly and consistently evaluate technology investment options. The decision aid includes the ability to automatically perform several deterministic and probabilistic sensitivity analyses.				
14. SUBJECT TERMS Decision Theory, Decision Support Systems, Fixed Wing Aircraft, Investments			15. NUMBER OF PAGES 112	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	